Elliott Bay Waterfront Recontamination Study

Volume I: Field Investigation Report

Results of Monitoring Conducted along the Central Seattle Waterfront - October 1993 to October 1994

Elliott Bay/Duwamish Restoration Program

Prepared for the
Elliott Bay/Duwamish Restoration Program Panel
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Abstract

The Washington State Department of Ecology conducted a year-long field investigation between October 1993 and October 1994 along the central Seattle Waterfront to identify potential sources of sediment recontamination, mechanisms of contaminant transport and resuspension, and sedimentation rates. The primary purpose of the study was to determine the feasibility of conducting sediment cleanup along the waterfront, at the request of the Elliott Bay/Duwamish Restoration Panel.

The field investigation focused on the nearshore waterfront area extending from Terminal 46 on the south to Pier 59 on the north. To characterize physical and chemical conditions in this area of Elliott Bay, settling particulate matter, bottom sediments, sediment cores, current velocity measurements and vertical profiles of light transmittance were collected between October 1993 and October 1994. Estimates of bottom sediment resuspension rates are also provided.

The data generated from the field investigation (Volume I) are combined with other available information on the area in Volume II of the Elliott Bay Waterfront Recontamination Study to develop a conceptual site model for the study area. This site model is then used to provide remedial design recommendations which will guide future sediment cleanup projects along the Seattle Waterfront.

Summary

Introduction

The Elliott Bay/Duwamish Restoration Panel, which is composed of federal, state, and local agencies, and tribes, was formed under the terms of a settlement of a Natural Resource Damage Assessment. The panel's primary mission is to conduct sediment cleanup and habitat restoration in areas of Elliott Bay and the Duwamish River associated with METRO and City of Seattle outfalls. Recent studies (Romberg, P., 1993a,b,c and Hart Crowser, 1990) have indicated that recontamination of sediments along the Seattle Waterfront is a concern and could affect the success of cleanup projects in the area. Based on this information, the Panel decided to conduct a resuspension/recontamination study prior to final selection of cleanup sites along the waterfront.

Objectives

The Elliott Bay Waterfront Recontamination Study was designed to evaluate the feasibility of undertaking sediment remediation projects within the central Seattle Waterfront area by 1997. More specifically the study was directed at meeting the following objectives:

- Measure the rate of recontamination and determine the rate of sedimentation/natural recovery.
- Identify the components of recontamination and quantify the contribution of each component to the extent possible, including an evaluation of uncertainties.
- Model the impact of these recontamination processes on potential sediment remediation options for the waterfront area.
- If the rate of recontamination is unacceptable, identify source control and/or resuspension control measures that would reduce recontamination to an acceptable rate.
- Based on the above, provide recommendations to the Panel on whether cleanup along the waterfront is feasible, the most appropriate project location(s) for sediment remediation, and the size and type of project(s) that would have the greatest chance of success.

The Recontamination Study was carried out in two phases. Phase I was a year-long field investigation (October 1993 to October 1994) designed to fill data gaps that have been identified along the Seattle Waterfront. Phase II combined the results of the field investigation with existing information to develop a conceptual site model for the area. The Department of Ecology was selected to oversee and manage the overall Recontamination Study and conduct the field

investigation. A modeling team, which consisted of a group of consultants, was contracted to perform modeling and provide remedial design recommendations. The results of this work are presented in Volume II of the Elliott Bay Waterfront Recontamination report.

During the process of scoping the field investigation the following data collection needs were identified to develop a conceptual site model:

- Characterize chemical concentrations (metals and organics) associated with settling particulate matter (SPM) at various points along the central Seattle Waterfront;
- Determine sediment accumulation rates in the study area, including an estimation of net sedimentation (deep burial) and resuspension (gross sedimentation minus net sedimentation);
- Estimate current velocity (speed and direction) in various portions of the nearshore waterfront area; and
- Identify sediment transport pathways and areas of deposition and erosion.

These data needs formed the basis of the field investigation study objectives. In addition, a number of studies were conducted in cooperation with the Recontamination Study to form a more comprehensive view of the processes occurring in Elliott Bay and the Duwamish River. These included a regional sediment transport study and two independent investigations of the effects of vessel prop wash on sediments.

Conclusions

In general, the spatial distribution of contaminants measured in SPM along the central Seattle Waterfront was in relatively good agreement with previous information on the area. Metals concentrations were fairly low and consistent during monitoring. An exception was mercury which exceeded Ecology's sediment Cleanup Screening Level (CSL) over a large portion of the study area (84% of the samples analyzed were >CSL). The average mercury concentration in SPM during the course of the study was 0.96 mg/kg, dry weight. This concentration is approximately 1.5 times higher than the CSL.

In contrast to metals, organics concentrations were variable both spatially and temporally along the waterfront. Peak concentrations of most organics tended to occur in the northern portion of the study area between Pier 52 (Ferry Terminal) and Pier 57. Concentrations of 18 individual organics exceeded levels in SPM which would be expected to produce some adverse effects on biological resources (the Sediment Quality Standard - SQS). Twelve of these compounds also exceeded the CSLs.

Vertical profiles in bottom cores indicate that in the northern portion of the study area (between Pier 52 and Pier 57) concentrations of most contaminants typically peak at depths ranging from 16 to 42 cm. In contrast, north of Pier 48 the highest concentrations were present in the top 7 cm. These data indicate that sediment cleanups in the northern portion of the study area that only involved sediment removal (i.e., dredging) would probably expose more highly contaminated material then currently exists at the surface.

Net current speeds (surface and bottom) at all locations were weak along the waterfront being <5.0 cm/sec. The mean net speed for the entire study period was 1.3 cm/sec. Although net speeds were weak, a number of short-term spikes (on the order of minutes) were observed in the current records. These maximums ranged from 5.8 to 135 cm/sec. The occurrence of spikes in the records suggests that short-term events such as vessel movements are affecting near bottom (3' above the bottom) current speeds.

Overall net current directions tend to be oriented parallel to the faces of piers. In addition a convergent zone which moves water offshore to the west in the vicinity of Pier 52 was present. This convergent zone located near Pier 52 appears to separate the study area hydrodynamically into a northern and southern region. The most likely explanation for the presence of this convergent zone is ferry operations at Pier 52. When docked, the ferries typically apply forward thrust to the stern propellers to hold the vessel in the berth during loading and unloading of cars and passengers. This causes an offshore current to be generated which moves away from Pier 52 to the west. The potential effects of vessel activities on nearshore currents is discussed in more detail in Volume II of the study report.

Gross sedimentation (net + resuspension) rates determined from bottom trap (3' above the bottom) data ranged from 0.3-1.8 g/cm^2/yr with a mean of 0.8±0.17 g/cm^2/yr. The highest rates were typically measured immediately south of the Seattle Ferry Terminal. Net sedimentation rates for the waterfront ranged from 0.1 - 0.72 g/cm^2/yr, with a mean of 0.28±0.26 g/cm^2/yr. Resuspension estimates for bottom sediments along the Seattle Waterfront ranged from 0.13±0.28 to 1.1±0.54 g/cm^2/yr.

Locations with the most variable gross sedimentation rates tended to correspond to areas with the highest amount of vessel traffic. These data in conjunction with current velocity measurements and ^{210}Pb results suggest that vessel movements play an important role in resuspending bottom sediments along the central Seattle Waterfront, especially during the summer and early fall.

In general, cores from the northern portion of the study area between Piers 54 and 57 exhibited vertical contaminant profiles with peak concentrations occurring at depth. This was especially true for mercury between Pier 56 and 57, where concentrations as high as 16 mg/kg, dry weight occurred at a depth of 105-168 cm. In contrast, maximum concentrations for most chemicals in a core collected north of Pier 48 occurred in the top 7 cm.

Recommendations

Based on the results of information collected during the field investigation portion of the Elliott Bay Waterfront Recontamination Study the following recommendations are made:

- Further evaluate the relative contributions of various bottom sediment resuspension processes such as vessel prop wash, vessel generated wakes, and wind generated waves. This information will be useful in the selection of appropriate remedial design options for the area.

- Evaluate the ability of selected sediment cleanup technologies to withstand vessel activities in the area. This would include an evaluation of design considerations such as water depth, appropriated capping materials (grain size), and necessary armoring to prevent erosion.

- Based on bottom current circulation patterns the northern (Pier 52 to Pier 59) and southern (Pier 52 to Pier 46) portions of the study area could probably be separated into distinct areas for remedial design purposes.

- In the northern portion of the study area, sediment removal alone (i.e., dredging) should not be used as a remediation technology due to the potential to expose more highly contaminated sediments.

A more detailed analysis of remedial design considerations is presented in Volume II of this report.

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1.0 Project Overview

This report presents the results of a field investigation conducted by the Washington State Department of Ecology (Ecology) to identify sources of recontamination along the Seattle waterfront, mechanisms of contaminant transport and resuspension, and sedimentation rates. The primary purpose of the Elliott Bay Waterfront Recontamination Study was to determine the feasibility of conducting sediment cleanup along the waterfront.

The study was funded by and conducted on behalf of the Elliott Bay/Duwamish Restoration Program Panel, which is composed of federal, state, and local agencies and tribes who have been entrusted with selecting areas for cleanup and habitat restoration in Elliott Bay and the Duwamish River. These activities are being conducted under a settlement between the federal, state, and tribal Natural Resource Trustees, METRO, and the City of Seattle. Cleanup and restoration activities under the settlement are to focus on areas associated with Combined Sewer Overflows (CSO) and storm drain outfalls operated by METRO and the City of Seattle.

The Panel has been evaluating potential cleanup sites in Elliott Bay and the Duwamish River, several of which are located along the central Seattle waterfront. Recent studies (Romberg, P., 1993a,b,c and Hart Crowser, 1990) suggested that recontamination of sediments along the waterfront was a concern and could affect the success of cleanup projects in the area. Based on this information, the Panel decided to conduct a resuspension/recontamination study prior to final selection of cleanup sites along the waterfront.

Potential sources of recontamination evaluated as part of the current study included ongoing discharges, local resuspension of contaminated sediments, and longshore transport of contaminated sediments from other areas (the Duwamish River to the south and contaminated shoreline to the north). The study focused on the nearshore waterfront area extending from Pier 48 on the south to Pier 59 on the north (see Figure 1), but included limited evaluation of more distant sources, including the Duwamish River plume and the Denny Way CSO.

Study Objectives

The Panel directed Ecology to provide preliminary information needed to answer the following general question by February 1995:

> **Is it feasible for the Panel to undertake sediment remediation projects within the waterfront area by 1997?**

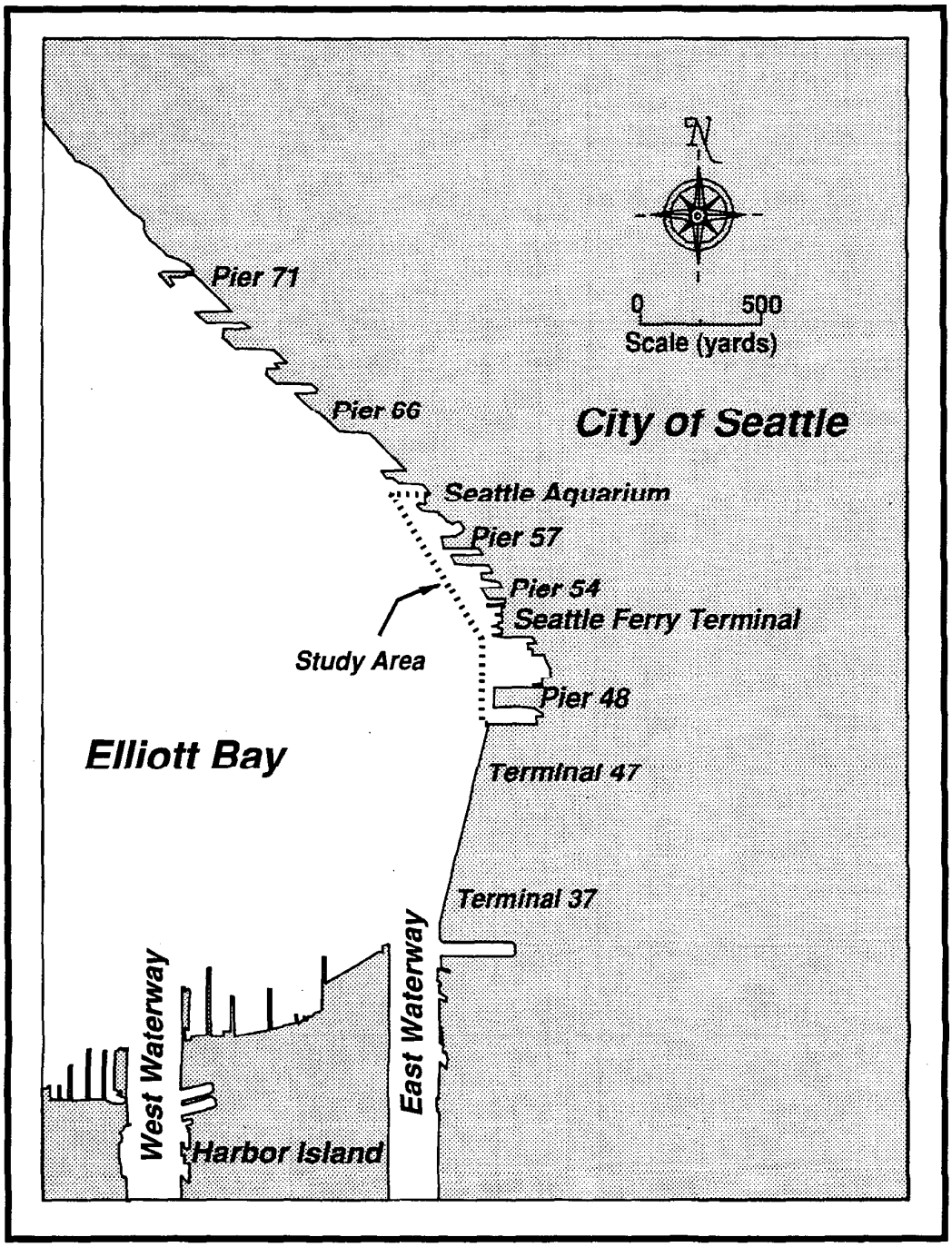


Figure 1: Elliott Bay Waterfront Recontamination Study Area.

More specifically, the waterfront study was directed toward meeting the objectives listed below:

- Measure the rate of recontamination and determine the rate of sedimentation/natural recovery.
- Identify the components of recontamination and quantify the contribution of each component to the extent possible, including an evaluation of uncertainties.
- Model the impact of these recontamination processes on potential sediment remediation options for the waterfront area.
- If the rate of recontamination is unacceptable, identify source control and/or resuspension control measures that would reduce recontamination to an acceptable rate.
- Based on the above, provide recommendations to the Panel on whether cleanup along the waterfront is feasible, the most appropriate project location(s) for sediment remediation, and the size and type of project(s) that would have the greatest chance of success.

Individual components of the overall recontamination study are described in the *Elliott Bay Waterfront Recontamination Study - Scope of Work* (Ecology, 1993). This volume of the study report discusses the results of a one-year field investigation (Phase I), which was focused on addressing the first two objectives described above. The following data collection needs were identified for the field investigation to achieve the overall objectives of the waterfront recontamination study:

- Characterize chemical concentrations (metals and organics) associated with settling particulate matter (SPM) at various points along the central Seattle Waterfront;
- Determine sediment accumulation rates in the study area, including an estimation of net sedimentation (deep burial) and resuspension (gross sedimentation - net sedimentation);
- Estimate current velocity (speed and direction) in various portions of the nearshore waterfront area; and
- Identify sediment transport pathways and areas of deposition and erosion.

Scoping Activities

A number of scoping activities were carried out before and during the field investigation to guide sampling activities and ensure that the field investigation would provide the data needed to answer the questions posed by the Panel. Prior to developing the sampling plan, a literature search was conducted to assist in identifying data gaps, selecting study locations, and interpreting results.

Topic areas covered by the literature search included currents, resuspension, distribution of suspended particulates, chemical analysis of suspended particulates, sediment trap studies, sediment accumulation rates, and bottom sediment surveys. For each subject area, a brief summary of current knowledge was prepared. In addition, ongoing monitoring activities along the waterfront were reviewed to determine whether data collected as part of these monitoring programs could be used to supplement the field investigation. A copy of the literature search is included in Appendix A, along with a detailed bibliography, keyed to topic areas.

A planning meeting was held on August 12, 1993 to scope the field investigation portion of the recontamination study. Participants in the planning meeting included Dr. Teresa Michelsen (Ecology overall project manager), Dale Norton (Ecology manager for the field investigation), Bob Clark (Panel representative), and nine additional local experts in the fields of sediment trap studies, sediment sampling, sediment transport, sedimentation rates, oceanography, geochemistry, aquatic chemistry, and modeling. The experts represent a wide range of relevant disciplines and include representatives of federal, state, and local agencies; academia; and consultants. An audience of approximately 50 people attended and provided additional input on the study design.

Prior to the meeting each participant was provided with a copy of the following background materials: description of the study objectives, the literature review, a proposed scope of work for the field investigation, an agenda, and questions for discussion. The experts were asked to follow up with written recommendations or comments within one week of the meeting. Meeting notes, along with the written recommendations of the experts, were used in revising the field investigation sampling plan.

In addition, a modeling team (Phase II) was selected in November 1993. This team provided valuable recommendations and mid-course corrections to the field study. Finally, the experts and interested audience participants were invited back to a presentation and discussion of the first six months of sampling results in July 1994, and a presentation of the final results in January 1995.

Modeling and Remedial Design Support

Volume II of the study report integrates the data collected during the field investigation with other available information (including a source control evaluation) and ongoing studies to develop a conceptual site model for the Seattle Waterfront. The potential effects of prop wash and wind waves are modeled and compared to data generated during the field investigation in Volume II of this report. Recommendations are made on areas that could effectively be cleaned up without significant recontamination. Finally, these data are used to provide recommendations on cap thickness and remedial technologies for areas under piers to provide support for the remedial design effort.

Related Studies

This investigation was conducted in cooperation with a number of studies that were ongoing simultaneously. The various studies, when taken together, provide a more comprehensive view of processes occurring in Elliott Bay and the Seattle Waterfront. These concurrent studies are briefly described below. In addition, information from these studies is evaluated along with data generated during the Waterfront Recontamination Study in Volume II of this report.

Regional Sediment Transport

A sediment transport study of Elliott Bay and the Duwamish River was conducted in October 1993 by GeoSea Consulting, and was partially funded by the Restoration Panel. The sediment transport study consisted of a grain size study of the Duwamish/Elliott Bay area to determine sediment transport pathways and potential linkages between contaminated sites in the region and areas of erosion, equilibrium, and sediment deposition. Results of the grain size study are provided separately in a report entitled *Sediment Transport in Elliott Bay and the Duwamish River: Implications to Estuarine Management* (GeoSea Consulting, 1994) and are discussed along with the results of this investigation in Volume II.

Vessel Prop Wash

Two independent investigations of the effects of prop wash on sediments along the Seattle Waterfront were undertaken during the study period. One modeling effort was conducted by the Washington State Department of Transportation (WDOT), Hart-Crowser, and Hartman Associates. This study was intended to determine the effects of the passenger-only ferries on contaminated bottom sediments south of the Seattle Ferry Terminal (Colman Dock- Pier 52). In addition, Michael Francisco (NOAA Panel secretary) completed a master's thesis for the University of Washington School of Marine Affairs entitled *Prop Wash Scour and the Management of Contaminated Sediments on the Seattle Central Waterfront* (Francisco, 1995). This investigation looked more widely at the potential for various vessels operating in or near the waterfront to resuspend contaminated sediments. Data were shared and jointly peer reviewed among these two investigations and the waterfront recontamination study. The data from all three investigations is discussed where relevant to the overall goals of the waterfront recontamination study in Volume II of this report.

2.0 Methods

Site Selection

Sampling locations for the field investigation are shown in Figure 2. These stations were selected to characterize spatial variability among different physical configurations occurring in the study area (*i.e.*, near CSO, under piers, within slips, and exposed pier faces). Detailed descriptions of each station and the purpose for its location are provided in Appendix B, Table B1.

Station positions were recorded with the use of a Magellan Nav 5000D® GPS receiver, in conjunction with depth readings. In addition, distances from fixed onshore structures were recorded. In general, water depths in the study area ranged from 23' (MLLW) to 72' (MLLW) with a mean of 42'. Generalized bathymetry for the study area is shown in Figure 3.

Sample Collection

To characterize conditions in the nearshore area of the central Seattle Waterfront settling particulate matter (SPM), bottom sediments, sediment cores, current velocity measurements and vertical profiles of light transmittance were collected between October 1993 and October 1994. To evaluate seasonal variations, the study period was divided into four sampling quarters: Quarter 1= October to December 1993; Quarter 2= January to April 1994; Quarter 3= May to July 1994; and Quarter 4= August to October 1994. Table 1 presents a summary of the sampling conducted for the field investigation. In addition, each component of the field investigation is briefly described below. All field work was conducted in accordance with procedures outlined in the *Elliott Bay Waterfront Recontamination Study: Sampling and Analysis Plan; and Health and Safety Plan.* A copy of the Sampling and Analysis plan (SAP) is included in Appendix A. Modifications to the SAP which occurred during the course of the study are also documented in Appendix A.

Sediment

Nearshore Grain Size Mapping

To define depositional and erosional environments within the study area and aid with selection of bottom core sampling points, 69 surface sediment samples (top 2 cm) were collected along 15 transects (north to south) and analyzed for grain size distribution (PSEP, 1986). Where feasible, spacing between stations was 40 yards moving offshore to a maximum depth of 60 feet and 50 yards between transects moving north to south. However, due to physical constraints

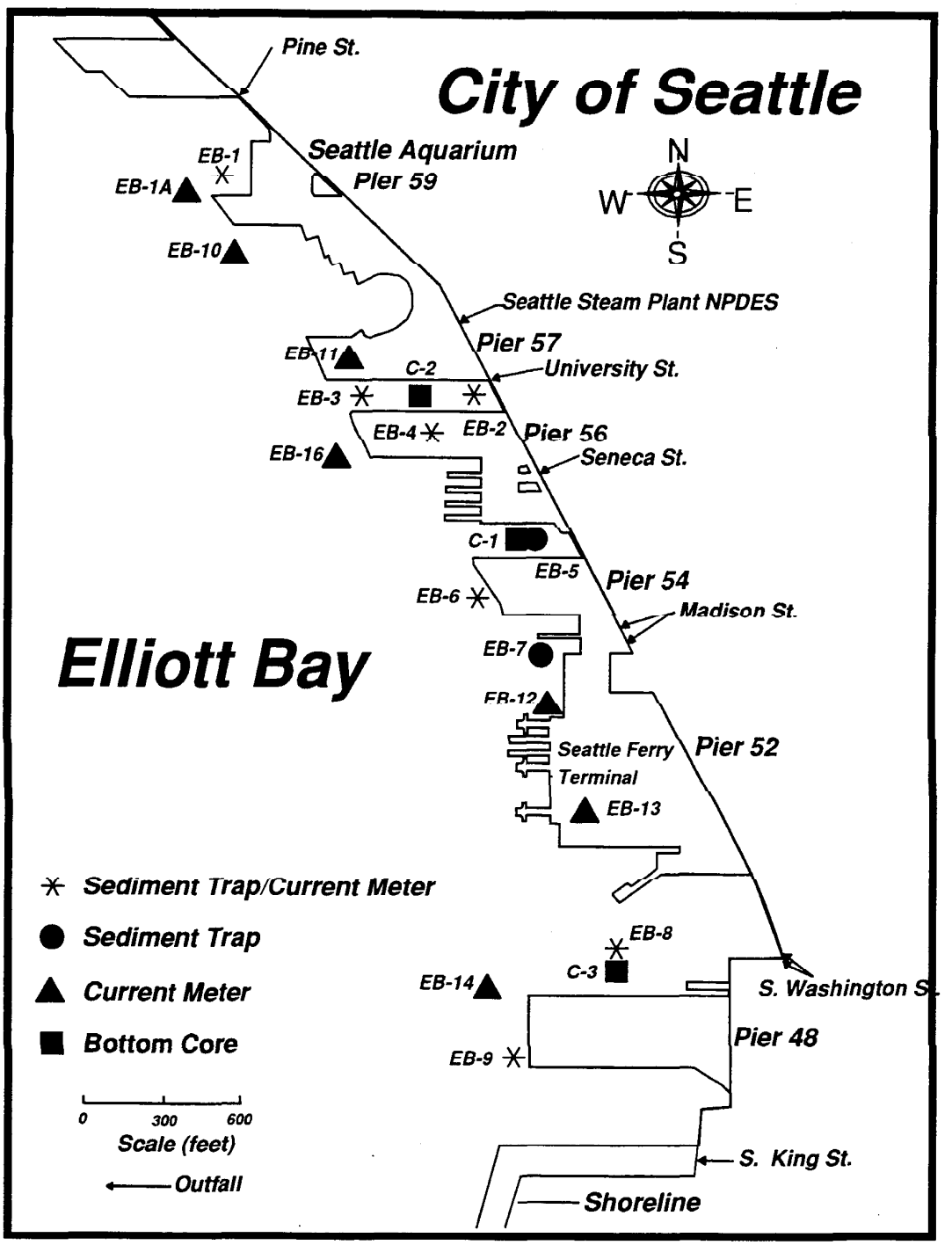


Figure 2: Station locations for the Elliott Bay Waterfront Recontamination Study.

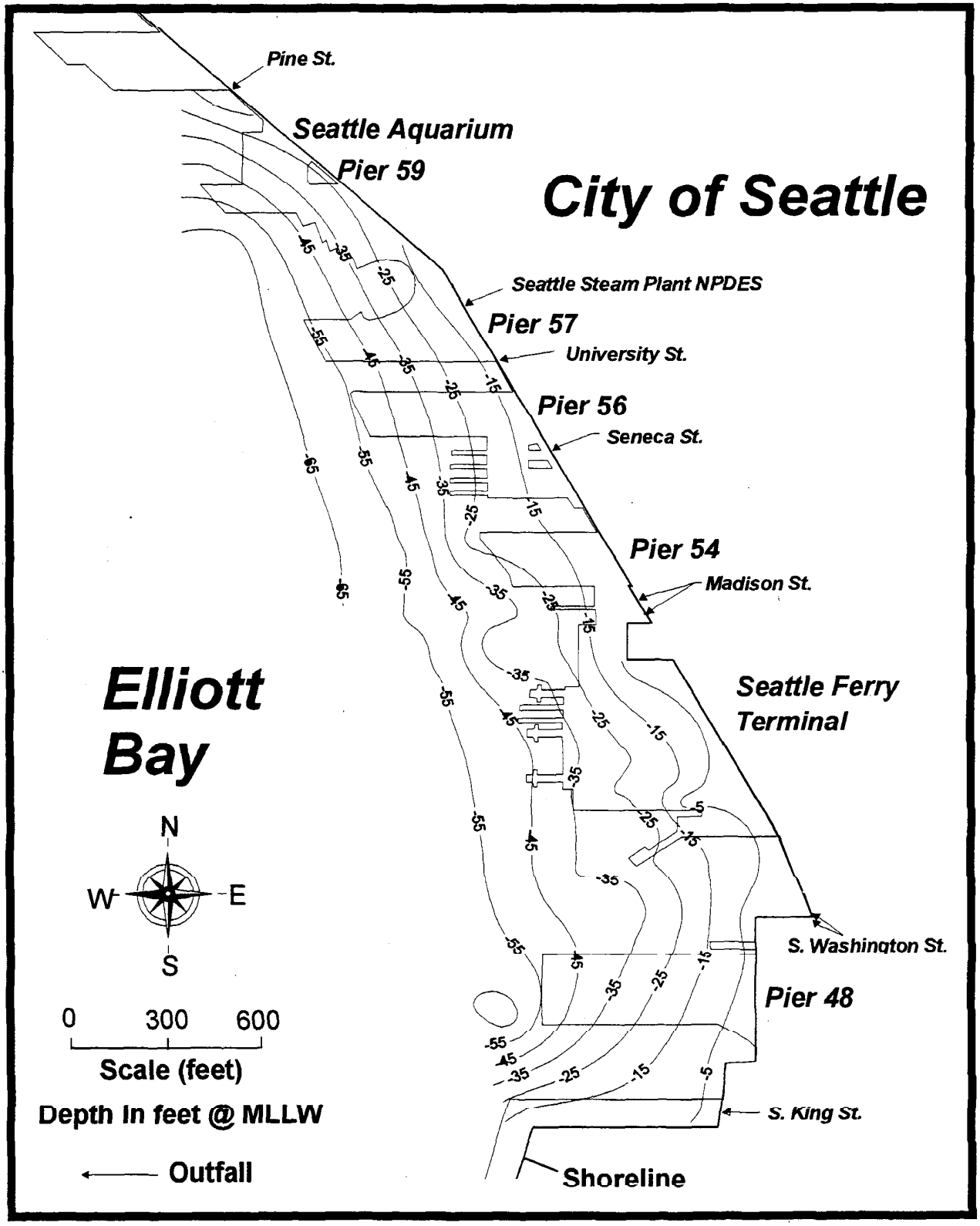


Figure 3: Bathymetry for the Elliott Bay Waterfront Recontamination Study area.

Table 1: Summary of sampling conducted for the Elliott Bay Waterfront Recontamination Study, October 1993 to October 1994.

Analysis	Sampler	Number Stations	Sampling Frequency	Duration of Deployments
I. WATER				
Light Transmittance	SeaTech 25cm Beam Transmissometer	One	Bi-weekly	Six Months
Current Velocity	Aanderra RCM-4	Six	Quarterly	One Year
" "	Interocean S4	Eleven	Monthly	Nine Months
II. SETTLING PARTICULATE MATTER				
Percent Solids	Sediment Traps	Nine	Quarterly	One Year
Grain Size	"	"	"	"
Total Organic Carbon	"	"	"	"
Total Metals				
Aluminum	"	"	"	"
Arsenic	"	"	"	"
Cadmium	"	"	"	"
Chromium	"	"	"	"
Copper	"	"	"	"
Iron	"	"	"	"
Lead	"	"	"	"
Manganese	"	"	"	"
Mercury	"	"	"	"
Silver	"	"	"	"
Zinc	"	"	"	"
Organics				
Semivolatiles	"	"	"	"
PCBs	"	"	"	"
Pb-210	"	"	"	"
III. BOTTOM SEDIMENT CORES				
Percent Solids	4" Barrel Core	Three	Once	N/A
Grain Size	"	"	"	"
Total Organic Carbon	"	"	"	"
Metals				
Aluminum	"	"	"	"
Copper	"	"	"	"
Iron	"	"	"	"
Lead	"	"	"	"
Manganese	"	"	"	"
Mercury	"	"	"	"
Zinc	"	"	"	"
Organics				
PCBs	"	"	"	"
Pb-210	"	"	"	"
Cs-137	"	"	"	"
IV. BOTTOM SEDIMENT				
Grain Size Mapping	Van Veen/Ponar	Sixty Nine	Once	N/A

encountered in the field this grid was modified. Final locations of the grain size stations are shown in Figure 4.

Settling Particulate Matter

At nine stations SPM was collected with the use of moored sediment traps positioned three feet above the bottom. In addition, to evaluate surface (low salinity) and bottom (high salinity) conditions, at two locations (EB-1 and EB-6) sediment traps were also deployed on floating moorings designed to keep the traps at a constant position of three feet below the water surface. The location of each of the sediment trap stations is shown in Figure 2. The traps were deployed beginning in October 1993 and sampled every three months thereafter, until October 1994. The deployment and retrieval schedule for each trap in shown in Appendix B, Table B2.

A diagram of the mooring configuration and construction details of the traps is shown in Appendix B, Figure B1. These traps have been used successfully by Ecology in the waterways of Commencement Bay over the past six years to monitor contaminant concentrations associated with SPM and estimate bottom sediment resuspension rates (Norton and Barnard, 1992a,b; Norton, 1993).

Briefly, the traps are straight-sided glass cylinders with a collection area of 78.5 cm^2 and a height to width ratio of 5. Each mooring holds two cylinders for a total collection area of 157 cm^2 per mooring. To collect enough material for quarterly analysis of all parameters and reduce the possibility of missing data points, two independent moorings were installed at each station.

Prior to deployment, the collection cylinders were cleaned with sequential washes of hot tap water/Liquinox® detergent, 10% nitric acid, distilled deionized water, and pesticide grade acetone, then wrapped in aluminum foil until used in the field. At deployment the traps were filled with two liters of high salinity distilled water (4% NaCl), which contains sodium azide (2%) as a preservative to reduce microbial degradation of the samples during the deployment period.

Upon retrieval of the traps, water overlying the sediment layer in the collection cylinders was removed with a peristaltic pump. The salinity of water immediately overlying the sediment layer was determined to see if the traps had been disturbed and preservative was still present. SPM was then transferred to 1/2 gallon sample containers and taken to the laboratory for processing, where the particulate fraction was isolated with the use of a centrifuge. Prior to determining sample weights and conducting physical and chemical analyses all visual nekton >2cm was removed from the samples.

Bottom Sediment Coring

To supplement existing data on the area, three sediment cores were collected for ^{210}Pb and ^{137}Cs

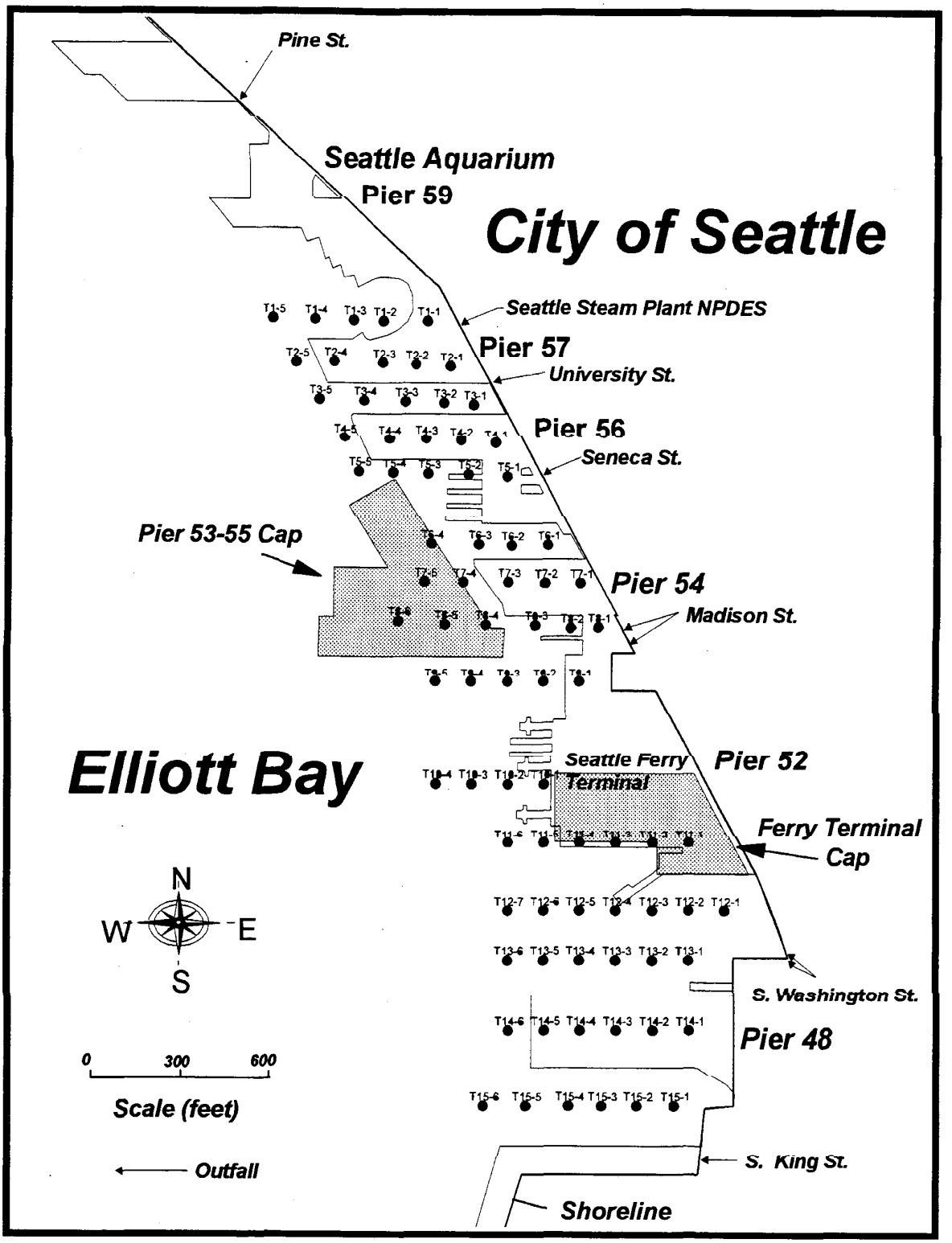


Figure 4: Grain size mapping stations for the Elliott Bay Waterfront Recontamination Study.

dating and selected chemical analysis. The location of the sediment cores are also shown in Figure 2.

All cores were collected using a gravity corer deployed from the *R/V Kittiwake*. The barrel corer was equipped with a stainless steel core cutter and brass core catcher mounted on the end of a four inch diameter by six foot long PVC barrel. Sediment recoveries obtained with this apparatus ranged in length from 84 to 155 cm (compacted).

Upon retrieval of the sampler both sediment penetration and sediment recovery were recorded before extruding the core onto a foil-lined table for processing. Each core was sectioned with the use of pre-cleaned stainless steel pie servers. Field logs for each of the cores, which describe the physical characteristics of the sediment obtained and the sections retained for analysis, are included in Appendix B.

Water

Current Velocity

Current velocity (speed and direction) measurements were made at a total of 14 stations described below. Aanderra® Model RCM-4 current meters were placed at six stations (EB-1, EB-1A, EB-3, EB-6, EB-8, and EB-9) to measure near bottom current velocities. These meters were deployed three feet off the bottom and sampled quarterly for a period of one year. The meter at station EB-1 was moved offshore to station EB-1A during the third and fourth quarter of monitoring to better reflect conditions outside the pier line. In addition to the bottom meters, at station EB-6 one meter was placed in the upper seven feet of the water column to measure surface current velocities. Each meter was set to take instantaneous readings every 15 minutes for all channels except current speed. Current speed was recorded as 15 minute averages.

Current velocity information from the first quarter of monitoring indicated that a significant portion of the current speeds in the study area was below the RCM4's recording threshold of 2.5 cm/sec. To better characterize current velocities <2.5 cm/sec, starting on January 28 and ending October 14 two Interocean® S4 current meters were rotated monthly among a total of 11 locations (EB-1A, EB-2, EB-4, EB-6 (surface), EB-6 (bottom), EB-8, EB-9, EB-10, EB-11, EB-12, EB-13, EB-14). The S4 meters were set to record one minute averages for all channels every 15 minutes.

In addition, to estimate the effects of vessel prop wash on bottom currents at two locations (EB-8 and EB-16) S4 current meters were deployed for two days between October 25-27 and set to record 30 second averages of current velocity continuously. This recording frequency was used to evaluate spikes anticipated from short-term events.

Transmissometers

An attempt was made to evaluate the height of sediment resuspension at station EB-6 with the use of three 25 cm beam transmissometers in a vertical array at three depths. Transmissometers were placed at heights of two feet, ten feet, and 20 feet above the bottom. These instruments were serviced (change batteries, clean optics, and download stored data) every two weeks, between January and June 1994.

Sample Handling

All sediment samples were placed in appropriate containers, properly labeled and held on ice in insulated coolers while in the field. Ice was kept in watertight bags to prevent potential contamination of the samples. SPM samples were frozen within 12 hours of collection until processed at the laboratory. All bottom sediment samples were held at 4°C and delivered fresh to the laboratory within 24 hours of collection.

Sample tracking procedures followed those outlined in the Manchester Laboratory Users Manual (Ecology, 1991a). Briefly, Chain-of-Custody forms were completed for each set of samples. The chief scientist was responsible for ensuring that these forms were properly completed and signed at the time of sample transfer.

Sample Analysis and Quality Assurance

All physical/chemical analyses of samples for the Elliott Bay Recontamination Study were conducted using procedures specified in the Puget Sound Protocols (PSEP. 1986) as amended and updated, except for Total Organic Carbon (TOC), which was analyzed according to the 1993 PSSDA modifications to the PSEP method. In addition, the type and frequency of laboratory quality assurance (QA) samples at a minimum followed those specified in the Manchester QA Manual (Ecology, 1988). Table 2 summarizes the analytical methods and laboratories used for the field investigation.

All laboratories conducting analyses for this study supplied information to support a QA1 review of the data as specified in *PSDDA Guidance Manual - Data Quality Evaluation for Proposed Dredged Material Disposal Projects* (PTI, 1989). Quality of the data sets were evaluated with the use of the following sample types: duplicates, matrix spikes, internal standards, surrogate spikes, reference materials and method blanks. QA samples and their frequency of analysis for this project are summarized in Appendix C, Table C1. Results of analysis of reference materials and blind field duplicates are also summarized in Appendix C, Tables C2-C4. A detailed QA review of each data set was performed by staff at the Ecology/EPA Manchester Laboratory. Individual case narratives for each data set are provided in Appendix C.

Table 2: Summary of analytical methods for Elliott Bay Waterfront Recontamination Study.

Analysis	Method	Reference	Laboratory
Percent Solids	Dry @ 104°C	PSEP, 1986	Ecology/EPA- Manchester, WA.
Grain Size	Seive and Pipet Apparent (w/o H2O2 addition) True (w/ H2O2 addition)	PSEP, 1986	Soil Technology Inc.- Bainbridge Is., WA.
Total Organic Carbon	Combustion/CO2 Measurement as modified by PSSDA	PSDDA, 1993	Weyerhaeuser Tech. Center- Tacoma, WA. Analytical Resources Inc.- Seattle, WA Sound Analytical Services- Tacoma, WA.
Total Metals			
Aluminum	ICP	EPA, 1986	Ecology/EPA- Manchester, WA.
Arsenic	GFAA	"	"
Cadmium	GFAA	"	"
Chromium	ICP	"	"
Copper	ICP	"	"
Iron	ICP	"	"
Lead	GFAA	"	"
Manganese	ICP	"	"
Mercury	CVAA	"	"
Silver	ICP	"	"
Zinc	ICP	"	"
Organics			
Semivolatiles	GC/MS #8270	EPA, 1986	Ecology/EPA- Manchester, WA.
PCBs	GC/ECD #8080	"	"
Radiodating			
Pb-210	Polonium-210 activity	Koide et.al., 1973	Battelle Northwest- Sequim, WA.
Cs-137	Gamma Spectroscopy	-	"

Overall, no major analytical problems were encountered in the analysis of samples for the study. Notable exceptions to this statement are discussed below. Consequently, the data generated are considered acceptable for use as qualified in the following data tables and noted in the case narratives (Appendix C).

Silver results for all collections are qualified as estimates based on low recoveries obtained in the analysis of matrix spikes and reference materials. It is believed that the results underestimate actual environmental levels Consequently the reported silver data should be used with caution. To a lesser extent, low spike recoveries were also obtained for arsenic in all SPM samples, mercury in SPM during the first quarter and lead and zinc in bottom cores. As a result, these data have also been qualified as estimated values. The reader is referred to Appendix C case narratives and Table C2 for more details.

Variable detection limits were obtained for a number of the semivolatile organics between monitoring quarters which hindered some data interpretations. The presence of high background concentrations of aromatic hydrocarbons, lipids, and sulfur in a number of the samples is the most likely explanation for the degradation in quantitation limits.

Unless otherwise noted all concentrations in this document are reported on a dry weight basis. All of the raw physical and chemical data generated during this study have been compiled in a separate data report. Limited copies of this data report are available by contacting Ecology's Publications Office (see inside front cover of this report).

Results and Discussion

Water

Transmissometers

Results of transmissometer measurements collected at the west end of Pier 54 were analyzed by Mike Francisco of NOAA and are discussed in Volume II of the report as part of the conceptual site model.

Current Velocity

To characterize current velocities (speed and direction) in the study area 39 current meter records were collected and analyzed. Table 3 presents a summary of the current meter data collected.

Examination of these data indicates that net current speeds (the sum of the vector additions of all current vectors contained in the usable record) are quite weak in the study area being <5.0 cm/sec. The net speed average for all records was 1.3 cm/sec. The highest net speeds were typically measured near the surface at the west end of Pier 54 (EB-6).

Although net speeds were low along the waterfront, a number of short-term spikes (on the order of minutes in duration) were observed in the current records. These maximums ranged from 5.8 to 135 cm/sec. The occurrence of spikes in the current records suggest that short-term events such as vessel movements along the waterfront are affecting near bottom current speeds. Current records for the study area are analyzed in greater detail in Volume II of this report.

Generalized net bottom current circulation patterns along the central Seattle Waterfront are shown in Figure 5. Several distinct patterns are evident in the bottom circulation patterns. Overall net current directions tend to be oriented parallel to the faces of piers. In addition a convergence zone which moves offshore to the west in the vicinity of Pier 52 is present. This convergent zone located near Pier 52 appears to separate the study area hydrodynamically into a northern and southern region.

From Pier 48 on the southern end of the study area net bottom currents outside the pier faces flow north until they reach Pier 52 (Seattle Ferry Terminal), at which point they turn west and move offshore. In contrast, between Piers 52 and 57 currents flow south from Pier 57 along the pier faces until they reach Pier 52, again turning west and moving offshore. The most likely explanation for the occurrence of this convergent zone is ferry operations at the Colman Dock. When docked, the ferries typically apply forward thrust to the stern propellers to hold the ferry in

Table 3: Summary of current velocity data collected for the Elliott Bay Waterfront Recontamination Study.

Station	Meter Type	Period of Record	Speed (cm/sec) Max.	Speed (cm/sec) Net	Net Dir. (deg/T)	Speed (cm/sec)* 0–2.5	2.5–5.0	5.0–7.5	7.5–10	10–12.5	12.5–15	15–17.5	17.5–20	>20
EB1	RCM4	10/20/93–1/10/94	20.7	0.35	177	62.4	25.6	8.3	2.7	0.7	0.2	0.05	0.05	0.03
EB1	RCM4	1/10–4/14/94	19.8	0.17	180	65.7	24.1	7.6	1.9	0.4	0.18	0.02	0.01	–
EB1A	RCM4	4/14–7/12/94	22.3	.4	319	70.0	14.0	8.8	4.6	1.9	0.69	0.16	0.04	0.01
EB1A	RCM4	7/12–10/10/94	17.8	0.85	302	84.4	9.2	4.2	1.4	0.5	0.16	0.03	0.01	–
EB1A	S4	10/13–25/94	11.2	0.80	297	52.0	39.3	7.5	1.0	0.2	–	–	–	–
EB2	S4	7/14–8/16/94	8.1	0.11	213	93.4	6.1	0.44	0.03	–	–	–	–	–
EB3	RCM4	10/13/93–1/12/94	28.3	1.02	227	51.4	27.2	13.0	5.0	2.0	0.89	0.32	0.2	0.16
EB3	RCM4	1/12–4/13/94	21.2	1.52	210	40.7	31.4	17.7	6.8	2.3	0.63	0.25	0.1	0.01
EB3	RCM4	5/7–7/14/94	26.9	1.25	215	44.2	30.9	15.3	5.8	2.2	0.97	0.37	0.18	0.13
EB3	RCM4	7/14–10/10/94	30.5	1.26	226	54.4	25.5	11.5	4.8	2.1	0.99	0.34	0.15	0.22
EB4	S4	1/28–3/15/94	5.8	0.36	266	97.3	2.6	0.1	–	–	–	–	–	–
EB6S	RCM4	10/20/93–1/11/94	45.7	3.72	242	4.1	3.5	3.8	5.9	10.3	14.0	14.9	13.5	30
EB6S	RCM4	1/11–3/9/94	47.5	3.05	268	0.86	3.0	6.0	10.5	15.5	19.7	17.2	10.1	17.3
EB6S	S4	6/16–7/13/94	20.7	0.56	284	35.7	46.5	13.3	2.8	1.2	0.3	0.2	0.04	0.04
EB6S	RCM4	4/11–5/8/94	40.4	3.07	267	0.72	5.1	10.7	15.5	17.0	15.2	13.0	9.1	13.7
EB6S	RCM4	7/14–7/27/94	45.7	4.98	266	–	0.3	0.3	1.4	8.6	11.5	16.0	17	45
EB6B	RCM4	10/20/93–1/12/94	20.4	0.87	149	56.7	30.6	9.4	2.6	0.5	0.1	0.06	0.01	0.01
EB6B	RCM4	1/11–4/11/94	37.3	2.2	155	24.0	32.5	26.3	12.7	3.8	0.62	0.09	0.03	0.04
EB6B	S4	5/16–6/16/94	13.2	0.81	162	63.3	29.9	5.9	0.7	0.2	0.03	–	–	–
EB6B	RCM4	4/13–7/11/94	16.1	1.02	139	61.8	28.0	8.0	1.7	0.34	0.14	0.03	–	–
EB6B	RCM4	7/11–9/26/94	27.8	0.35	158	64.5	21.9	8.8	2.9	1.1	0.5	0.15	0.11	0.26
EB8	RCM4	10/12/93–12/29/93	17.7	0.12	331	89.9	6.9	2	0.9	0.2	0.07	–	0.01	–
EB8	RCM4	1/11–2/18/94	10.6	1.61	178	97.0	2.5	0.45	0.2	0.03	–	–	–	–
EB8	RCM4	3/2–4/14/94	18.5	2.37	357	70.3	22.3	5.5	1.2	0.39	0.19	0.05	0.05	–
EB8	S4	4/15–5/16/94	24.8	0.96	138	70.2	25.6	3.5	0.3	0.3	0.1	–	–	0.06
EB8	RCM4	4/14–7/13/94	24.8	0.29	147	88.0	7.3	2.3	1.3	0.46	0.24	0.08	0.08	0.03
EB8	RCM4	7/13–8/22/94	21.8	0.30	194	81.0	11.3	4.5	1.9	0.86	0.23	0.18	0.05	0.03
EB8	S4	10/27–10/30/94	7.5	0.30	170	85.6	13.2	0.87	–	–	–	–	–	–
EB9	RCM4	10/12/93–1/10/94	16.3	0.45	038	98.9	0.7	0.3	0.5	0.03	–	0.01	–	–
EB9	RCM4	1/10–4/15/94	21.6	1.24	284	98.4	0.84	0.35	0.17	0.1	0.09	0.01	–	0.02
EB9	S4	3/15–4/15/94	52.7	1.31	353	77.9	19.5	1.5	0.3	0.2	–	0.1	–	0.3
EB9	RCM4	4/15–7/12/94	20.5	0.41	042	97.5	1.54	0.45	0.24	0.15	0.04	0.02	0.04	0.01
EB9	RCM4	7/12–10/12/94	25.6	0.72	002	97.0	1.5	0.6	0.39	0.29	0.15	0.03	0.01	0.02
EB10	S4	7/14–8/16/94	28.0	3.5	248	27.5	46.8	20.4	4.2	0.73	0.22	0.09	0.06	0.06
EB11	S4	9/25–10/13/94	135	0.64	162	83.0	15.4	0.74	0.23	0.6	–	0.06	0.06	0.11
EB12	S4	8/16–9/20/94	28.2	0.30	247	45.4	34.3	13.2	4.3	1.9	0.65	0.24	–	0.09
EB13	S4	8/16–9/20/94	11.7	2.79	276	30.4	59.4	9.2	0.92	0.12	–	–	–	–
EB14	S4	6/16–7/13/94	20.9	1.75	003	55.3	33.4	8.9	1.7	0.4	0.1	0.1	0.04	0.04
EB16	S4	10/25–10/27/94	14.4	0.34	150	55.2	29.0	12.1	2.9	0.8	0.1	–	–	–

*= Values shown represent percent of values in speed range
RCM4= Aanderra Instruments RCM4 current meter
S4= Interocean S4 current meter

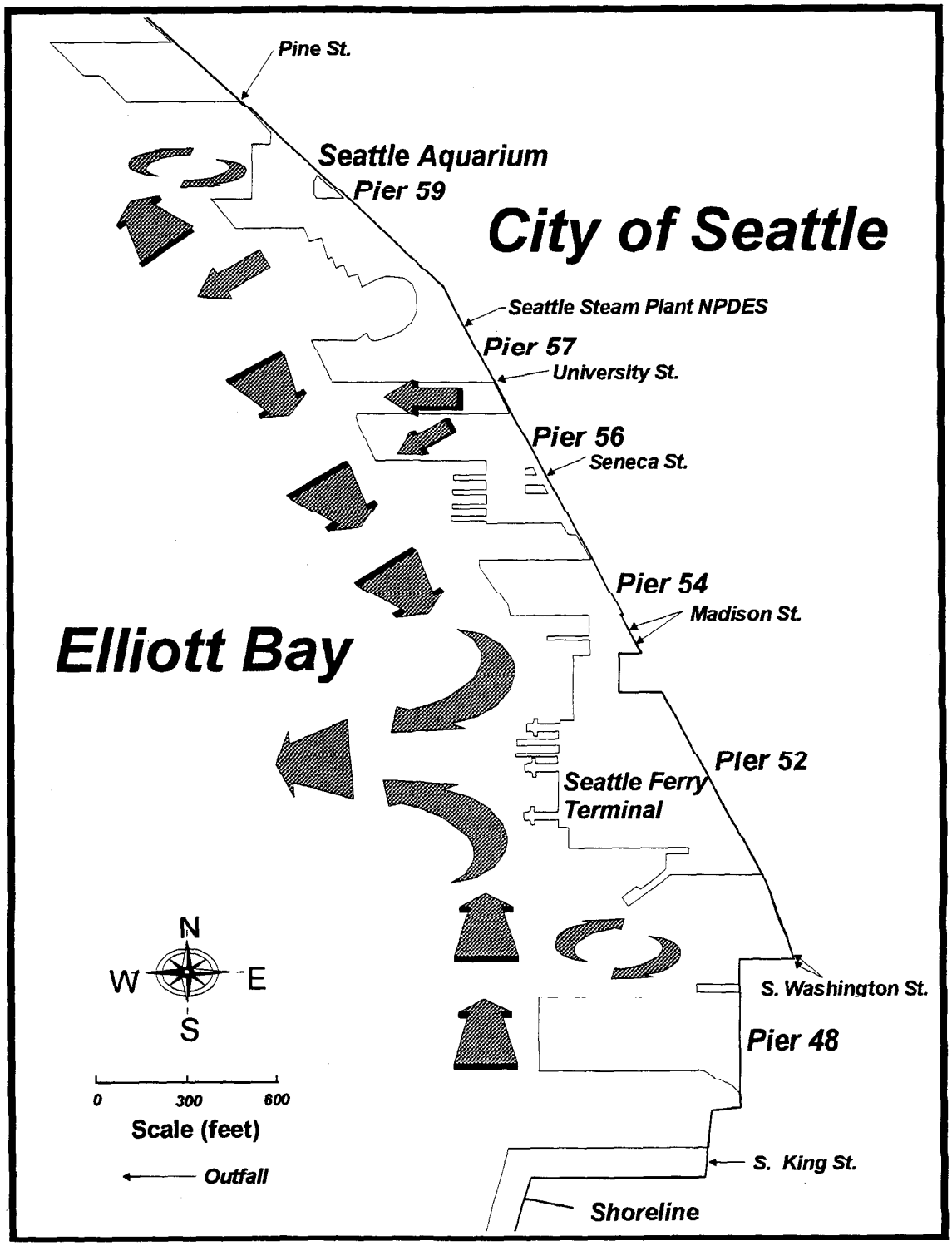


Figure 5: Generalized bottom current circulation from net currents.

the berth during loading and unloading. This results in a offshore current being generated which moves away from Pier 52 to the west. The reader is again referred to Volume II of this report for a more detailed discussion of the impacts of vessels on nearshore currents.

In the vicinity of Pier 59 the dominate net current direction is again to the north with a small offshore current occurring just south of Pier 59. Small clockwise gyres are also indicated inside the outer pier limits at two locations: north of Pier 59 and between Piers 48 and 52. Within the slip between Pier 56 and 57 the dominant current direction is westerly. Currents are discussed in greater detail as part of the conceptual site model in Volume II.

Settling Particulate Matter (SPM)

Distribution of Contaminants

Out of 88 sediment traps deployed for the recontamination study, 86 were successfully recovered (98%). The results of conventionals (percent solids, grain size and total organic carbon), and metals analysis of SPM samples collected between October 1993 and October 1994 are shown in Appendix D, Table D1.

Percent solids concentrations (post-centrifugation) measured over the study period ranged from 15 to 36%. Grain size analysis indicates that the sediment trap samples were relatively consistent in their composition containing primarily silt and clay size particles (<62um). For most stations the percentage of sand size (>62um) particles increased during the fourth quarter of monitoring. TOC levels in SPM were somewhat variable throughout the study period ranging from 3.2 to 18.7% with a mean of 7.2%. TOC concentrations in excess of 10% were measured at two locations along the waterfront, EB-2 and EB-5. These high values are believed to be attributed to the presence of decomposing marine organisms (primarily squid) that had entered the sediment trap cylinders and expired.

Summarized below are selected metals concentrations in SPM from the central Seattle Waterfront:

Summary of selected metals in SPM (mg/kg, dry weight).

Metal	Range	Mean	C.V.	N
Arsenic	5.2-41	16	0.37	44
Cadmium	0.56-4.5	1.7	0.47	44
Chromium	24-650	67	1.4	44
Copper	85-390	140	0.40	44
Lead	63-200	120	0.28	44
Mercury	0.25-4.4	0.96	0.70	44
Silver	0.3-5.2	1.6	0.66	44
Zinc	130-390	230	0.24	44

C.V.= Coefficient of variation (std/mean)
N= Number of samples

Metals concentrations in SPM were generally low and fairly consistent along the Seattle Waterfront throughout the monitoring period. Overall, most metals concentrations varied by less than a factor of 8. An exception was mercury which varied by more than an order of magnitude. Mercury concentrations on a dry weight basis ranged from 0.25 to 4.4 mg/kg with a mean of 0.96 mg/kg. The highest values were consistently measured at the head of the slip between Piers 56 and 57. The lowest values typically occurred in surface samples collected near Pier 59. A similar distribution to mercury was observed for silver with the highest concentrations occurring at station EB-2. Silver was not detected in surface samples near Pier 59.

Anomalously high concentrations of copper and chromium were seen during the first quarter of monitoring at stations EB-2 and EB-6 (surface), respectively. While there is no strong analytical evidence to discount these measurements, they do not appear to fit the pattern of other measurements at these locations. For perspective, copper during the first quarter at EB-2 was elevated by a factor of 2 compared to other values at this location. The anomalously high chromium value (650 mg/kg, dry weight) is approximately an order of magnitude higher than the overall mean (67 mg/kg, dry weight) recorded for all monitoring stations.

Appendix D, Table D2 summarizes the results of semivolatile organics and polychlorinated biphenyls (PCB) analysis of SPM samples on a dry weight basis. Thirty-four target organics were detected in SPM during the course of monitoring. Detected concentrations of selected organics in mg/kg, dry weight are summarized below:

Summary of selected organics detected in SPM (ug/kg, dry weight).

Compound	Range	Mean	C.V.	Detection Frequency	N
LPAH	6.9-180	53	0.78	100%	41
HPAH	15-210	86	0.55	100%	41
Dibenzofuran	0.57-19	3.8	0.93	100%	41
2-Methylnapthalene	0.25-9.6	2.9	1.1	98%	40
Pentachlorophenol	0.32-1.9	0.85	0.70	24%	10
Bis(2EH)phthalate	2.8-91	13	1.7	37%	15
Benzoic Acid	1.6-8.8	4.7	0.45	46%	19
Total PCBs	0.13-1.1	0.52	0.37	90%	37

C.V.= Coefficient of variation (std/mean)
N= Number of samples

In contrast to metals, organics concentrations were variable both spatially and temporally along the waterfront. Peak concentrations of most organics tended to occur in the northern portion of the study area between Pier 57 and 52 (Ferry Terminal). In particular, maximum concentrations of polynuclear aromatic hydrocarbons (PAHs) and several chemically related compounds (dibenzofuran, 2-methylnapthalene, and carbazole) occurred in the vicinity of Piers 56 and 57. The lowest concentrations of most organics were typically found south of the ferry terminal in the vicinity of Pier 48. Exceptions to this pattern were 4-methylphenol and bis(2-ethyl hexyl)phthalate which peaked south of the ferry terminal, at station EB-8. Pentachlorophenol was only detected in the northern portion of the study area between Piers 59 and 54 (Stations EB-1 to EB-5). Relatively low concentrations of PCBs were detected throughout the study area. Concentrations of most organics detected were higher in bottom traps than in surface traps at concurrent locations during all monitoring quarters.

At all stations, the sum of HPAH (high molecular weight PAH) exceeded the sum of LPAH (low molecular weight PAH). This enrichment of HPAH in SPM is not unexpected since weathering processes such as evaporation, photochemical oxidation, dissolution, and microbial degradation can preferentially remove PAHs with molecular weights less than that of fluoranthene (Merill and Wade, 1985). The apparent enrichment of HPAHs relative to LPAHs would suggest that historical sources of these compounds have played an important role in the PAH contamination of sediments observed along the waterfront.

Additional organics detected in SPM included: isophorone, retene, 1,4 dichlorobenzene, phenol, 4,6 dinitro-2-methylphenol, benzyl alcohol, benzoic acid, di-n-butylphthalate, di-n-octylphthalate, and butylbenyl phthalate. All these compounds were detected in <50% of the samples analyzed with the exception of retene, which had a detection frequency of 68%. Background information on several of these compounds is provided below.

Isophorone is used as a solvent for polyvinyl and nitrocellulose resins and lacquer finishes. Benzyl alcohol is used in perfumes and a variety of flavors. Benzoic acid is a naturally occurring compound which has several uses including: food preservative, manufacture of alkyl resins, production of phenol, and as a plasticizer to manufacture or modify resins such as PVC. 1,4 dichlorobenzene is a component of moth repellents, as well as air and toilet deodorizers (Verschueren, 1983). Phthalates are used extensively as plasticizers and are present in a wide variety of plastic products. In addition, they are used in the manufacture of non-plastic products such as lubricating oils and insecticides. Retene is a naturally occurring resin acid-derived compound that is commonly associated with wood waste (Prahl and Carpenter, 1984).

Temporally, intra-station concentrations of most organics tended to be somewhat variable. PAH concentrations most commonly peaked during the second quarter of monitoring (February to April) when normalized to organic carbon content. This pattern is no doubt related to the fact that TOC levels were also at a minimum during the second quarter of monitoring. While less variable than PAH concentrations a similar pattern was seen for PCBs, with maximum levels typically occurring in the second quarter. Organic carbon normalization reduces the variability in organics concentrations associated with differences in sediment TOC content. No consistent seasonal pattern was evident for most of the other organic compounds detected. However, differences in quantitation limits among monitoring quarters hinder interpretations of temporal trends for several of these organics.

Comparisons to Sediment Management Standards

In 1991, Ecology adopted the Sediment Management Standards (SMS), WAC 173-204. These standards identified specific contaminant levels below which no adverse effects would be observed in benthic communities, the "Sediment Quality Standards (SQS)". The standards also established "Cleanup Screening Levels (CSL)" which represent the upper limit of allowable minor adverse effects on biological resources. Contaminant concentrations above the CSLs are a high priority for remediation activities.

Contaminant concentrations in SPM from the central Seattle Waterfront are compared to the SMS in Tables 4 and 5. Chemicals which exceeded the SQS are summarized in Table 6. Concentrations of 18 individual compounds exceeded the SQS in SPM. The widest suite of exceedences was observed at the head of the slip between Pier 56 and 57 (EB-2), where 13 individual chemicals were above the SQS. All stations had at least seven chemicals above the SQS. The most widespread contaminant was mercury which was above the SQS in 89% of the samples analyzed. PAHs and to a lesser extent dibenzofuran were also above the SQS at all locations. PCBs only exceeded the SQS near Pier 59 and south of the ferry terminal at station EB-8.

Listed in Table 7 are chemicals which also exceeded the CSL in SPM. Fifteen chemicals fall into this category. The greatest number of exceedences were again measured in the vicinity of Pier 56

Table 4: Comparison of metals in settling particulate matter (SPM) to Ecology's Sediment Management Standards.

Station	Quarter	Solids (%)	Grain Size (%) Sand >62um	Silt 62–4um	Clay <4um	TOC (%)	Total Metals (mg/kg, dry weight) As	Cd	Cr	Cu	Pb	Hg	Ag	Zn	Al	Fe	Mn
EB1–Surface	1	27	–	–	–	7.5	41	1.6 j	74	200	140	0.41 j	0.3 uj	390	21000	41000	1300
	2	28	10	31	59	4.8	23 j	1.5	43	130	100	0.30	0.3 uj	290	20000	34000	960
	3	16	11	33	56	8.4	14 j	1.3	24 j	100	70	0.25 j	0.3 uj	200 j	9500	22000	400 j
	4	15	27	23	50	8.6	12 j	1.1	26	88	63	0.32 j	0.3 uj	170	8600	16000	390
EB1–Bottom	1	31	–	–	–	6.3	18	1.0 j	80	110	130	0.71 j	1.1 j	200	25000	33000	1000
	2	33	8	48	44	3.4	13 j	1.1	54	120	110	0.54	0.5 j	220	21000	31000	720
	3	20	8	37	55	6.1	12 j	1.0	30 j	86 j	93 j	0.61	1 j	150 j	11000	21000	340 j
	4	23	–	–	–	6.8	15 j	1.5	47	130	130	0.74	0.5 j	200	16000	29000	520
EB2	1	25	–	–	–	18.7	17	4.5 j	66	390	130	2.4 j	2.0 j	280	17000	26000	260
	2	23	10	40	50	6.8	18 j	2.6	68	190	180	1.5	2.0 j	310	20000	32000	690
	3	24	11	37	52	9.7	16 j	2.7	42 j	150 j	160 j	4.4 j	3.7 j	260 j	15000	25000	350 j
	4	23	19	42	39	11	19 j	3.7	48	190	170	2.0	0.64 j	300	16000	27000	370
EB3	1	29	–	–	–	6.7	22	1.4 j	80	130	140	0.85 j	1.4 j	220	27000	30000	1100
	2	32	9	43	48	6.3	16 j	1.2	70	120	110	0.80	1.3 j	200	22000	28000	1000
	3	24	8	35	57	7	12 j	1.3	38 j	110 j	100 j	0.94	1.8 j	170 j	17000	24000	7800
	4	22	13	37	50	8.4	15 j	1.7	41	120	120	0.79	0.95 j	210	17000	26000	560
EB4	1	27	–	–	–	8.7	26	2.0 j	79	150	130	0.92 j	1.5 j	240	25000	35000	1200
	2	30	10	34	56	5.1	18 j	1.7	59	140	120	0.73	1.4 j	250	23000	33000	1100
	3	23	7	34	59	8.5	15 j	1.7	39 j	130 j	120 j	1.4	2.7 j	210 j	17000	27000	470 j
	4	22	14	33	53	8.7	16 j	2.1	36	120	110	0.95	0.99 j	190	15000	24000	560
EB5	1	27	8	41	51	10.7	26	2.8 j	88	190	150	1.1 j	2.5 j	280	24000	35000	620
	2	25	8	45	47	6.4	18 j	2.1	57	170	140	0.94	2.2 j	270	19000	30000	670
	3	23	7	40	53	9.5	16 j	2.7	49 j	170 j	140 j	1.3	3 j	260 j	18000	29000	390 j
	4	25	16	39	45	9.9	19 j	3.2	55	170	150	1.1	2 j	270	20000	30000	340
SMS-SQS		–	–	–	–	–	57	5.1	260	390	450	0.41	6.1	410	–	–	–
SMS-CSL		–	–	–	–	–	93	6.7	270	390	530	0.59	6.1	960	–	–	–

j= Estimated value

uj= Estimated detection limit

SMS= Ecology Sediment Management Standards (WAC 173-204)

SQS= Sediment Quality Standards

CSL= Cleanup Screening Levels

=Exceeds CSL

Quarter 1= Oct to Dec 1993

Quarter 2= Jan to April 1994

Quarter 3= May to July 1994

Quarter 4= August to Oct 1994

Table 4 (cont.): Comparison of metals in settling particulate matter (SPM) to Ecology's Sediment Management Standards.

			Grain Size (%)				Total Metals (mg/kg, dry weight)										
Station	Quarter	Solids (%)	Sand >62um	Silt 62–4um	Clay <4um	TOC (%)	As	Cd	Cr	Cu	Pb	Hg	Ag	Zn	Al	Fe	Mn
EB6–Surface	1	26	–	–	–	–	22	2.0 j	650	140	150	0.38 j	0.5 j	280	24000	35000	300
	2	22	–	–	–	4.2	18 j	1.0	56	130	100	0.7	0.3 j	350	21000	33000	520
	3	20	6	36	58	7.3	8.6 j	1.4	25 j	85 j	63 j	1.1	0.52 j	170 j	11000	18000	130 j
	4	19	14	27	59	9.8	13 j	1.5	32	90	77	0.33	0.53 j	170	12000	18000	440
EB6–Bottom	1	28	–	–	–	6.4	23	1.4 j	98	130	120	0.93 j	1.2 j	210	22000	35000	1300
	2	27	11	41	48	4.7	14 j	1.0	50	120	100	0.66	1.1 j	200	19000	29000	790
	3	21	10	37	53	7.1	12 j	1.2	36 j	110 j	90 j	0.75	1.5 j	170 j	15000	24000	410 j
	4	23	24	36	40	7.6	11 j	1.6	39	120	100	0.63	1.5 j	180	16000	23000	370
EB7	1	29	–	–	–	7.3	23	0.98 j	83	140	150	0.84 j	2.2 j	240	24000	36000	860
	2	32	19	38	43	3.8	14 j	1.3	61	150	130	0.64	1.7 j	240	21000	31000	740
	3	23	15	38	47	7.1	12 j	1.4	40 j	110 j	110 j	0.86	2.4 j	190 j	14000	23000	360 j
	4	25	18	42	40	7.0	12 j	2.2	48	140	150	0.96	0.65 j	230	17000	26000	290
EB8	1	32	–	–	–	8.9	12	1.6 j	67	340	190	1.2 j	5.2 j	280	19000	31000	270
	2	34	12	47	41	4.5	16 j	1.3	61	190	200	1.2	3.0 j	240	20000	27000	460
	3	36	11	44	45	5.1	12 j	1.0	41 j	120 j	150 j	1.1	3.3 j	170 j	14000	22000	260 j
	4	36	23	47	30	4.5	5.2 j	1.7	40	130	200	1.4	3.1 j	220	13000	14000	330
EB9	1	35	–	–	–	4.2	15	0.65 j	100	180	98	0.66 j	1.5 j	190	22000	29000	1200
	2	33	10	46	44	3.2	10 j	0.56	51	100	94	0.62	1.2 j	170	21000	24000	860
	3	20	12	39	49	4.5	7.7 j	1.3	30 j	95 j	65 j	0.5	1.8 j	130 j	14000	19000	370 j
	4	22	10	42	48	7.7	11 j	0.95	42	120	94	0.67	1.7 j	170	20000	25000	850
Overall Mean		24	12	39	49	7.2	16 j	1.7 j	67	140 j	120 j	0.96 j	1.6 j	230 j	18000	28000	780 j
SMS-SQS		-	–	–	–	–	57	5.1	260	390	450	0.41	6.1	410	-	–	–
SMS-CSL		-	–	–	–	–	93	6.7	270	390	530	0.59	6.1	960	-	–	–

j= Estimated value

uj= Estimated detection limit

SMS= Ecology Sediment Management Standards (WAC 173–204)

SQS= Sediment Quality Standards

CSL= Cleanup Screening Levels

=Exceeds CSL

Quarter 1= Oct to Dec 1993

Quarter 2= Jan to April 1994

Quarter 3= May to July 1994

Quarter 4= August to Oct 1994

Table 5: Comparison of semivolatile organics detected in settling particulate matter to Ecology's Sediment Management Standards.

Station	EB1				EB1				EB2				SMS	
Depth	Surface	–	–	–	Bottom	–	–	–	Bottom	–	–	–		
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	SQS	CSL
TOC (%)	7.5	4.8	8.4	8.6	6.3	3.4	6.1	6.8	18.7	6.8	9.7	11	–	–
DRY WEIGHT NORMALIZED CONCENTRATIONS (UG/KG)														
Phenol	120 j	79 j	1100 u	540 uj	–	140 j	940 uj	520 uj	–	600 u	640 uj	3200	420	1200
4-Methylphenol	97 j	380 u	1100 u	540 u	–	350 u	940 uj	520 uj	–	600 u	640 uj	5100	670	670
Pentachlorophenol	900	1300	1200 j	6500 uj	–	350 j	9400 uj	5200 uj	–	1600 j	6400 uj	1400 uj	360	690
Benzyl Alcohol	81 j	380 uj	2100 u	540 u	–	13000 j	1900 u	520 uj	–	600 u	1300 u	270 u	57	73
Benzoic Acid	6800	2600 uj	6900 j	16000 uj	–	350 uj	2700 j	5200 uj	–	600 uj	2300 j	8800	650	650
ORGANIC CARBON NORMALIZED CONCENTRATIONS (MG COMPOUND/KG ORGANIC CARBON)														
Sum LPAH	390	230 j	120 j	190 j	–	740	330 j	470	–	1100	450	610	370	780
Sum HPAH	950	710	390	560	–	2000	890 j	1300	–	2100	730	1200	960	5300
2-Methylnaphthalene	16	6 j	4 j	5 j	–	23	14 j	25	–	43	32	29 uj	38	64
Dibenzofuran	24	12	7 j	9	–	38	20	34	–	72	39	43	15	58
1,4-Dichlorobenzene	2 u	8 u	13 u	6 u	–	10 u	15 u	8 u	–	6 j	4 j	5	3.1	9
Di-n-butylphthalate	3 uj	9 uj	13 uj	6 u	–	10 u	15 u	8 u	–	9 u	7 uj	2 u	220	1700
Di-n-octylphthalate	2 u	10	25 u	31 uj	–	10 u	69	38 uj	–	9 u	13 u	13 uj	58	4500
Butylbenzylphthalate	2 u	9 uj	13 u	31 uj	–	10 u	15 u	38 uj	–	9 u	7	13 uj	4.9	64
Bis(2EH)phthalate	130 uj	230	1200 u	24 uj	–	82	75 uj	15 uj	–	130	66 uj	65 j	47	78
Total PCBs	7	10	6	5 j	–	12	11	16 j	–	–	7	8	12	65

u=Not detected at detection limit shown

j=Estimated concentration

SMS= Sediment Management Standards (WAC 204-173)

SQS= Sediment Quality Standards

CSL= Cleanup Screening Level

=Exceeds Cleanup Screening Level

uj=Estimated detection limit

–=No sample

Quarter 1= Oct to Dec 1993

Quarter 2= Jan to April 1994

Quarter 3= May to July 1994

Quarter 4= August to Oct 1994

Table 5(cont.): Comparison of semivolatile organics detected in settling particulate matter to Ecology's Sediment Management Standards.

Station	EB3				EB4				EB5				SMS	
Depth	Bottom	–	–	–	Botom	–	–	–	Bottom	–	–	–		
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	SQS	CSL
TOC (%)	6.7	3.6	7.0	8.4	8.7	5.1	8.5	8.7	10.7	6.4	9.5	9.9		
DRY WEIGHT NORMALIZED CONCENTRATIONS														
Phenol	82 j	76 j	820 uj	800 uj	110 j	120 j	750 uj	390 uj	160	890 u	780 uj	320 u	420	1200
4-Methylphenol	74 j	450 u	820 u	870 j	120 j	580 u	730 j	390 uj	2100	890 u	780 uj	340 uj	670	670
Pentachlorophenol	440 j	320 j	8200 uj	2900 uj	540 j	340 j	7500 uj	2100 uj	690 u	890 u	480 j	3200 uj	360	690
Benzyl Alcohol	150 j	450 u	1700 u	440 u	210 u	7600 uj	1500 u	390 u	140 u	4700 uj	1600 u	320 u	57	73
Benzoic Acid	3500	2500 uj	3700 j	6900 uj	6600	580 u	5600 j	4600 uj	3400	890 u	6000 j	3200 uj	650	650
ORGANIC CARBON NORMALIZED CONCENTRATIONS														
Sum LPAH	1300	2400	840 j	820	2000	2000	1300	2100 j	1200	1500	620	540	370	780
Sum HPAH	1900	3600	1100 j	1200	2400	2700	1300	2100	1700	2200	960	1000	960	5300
2-Methylnaphthalene	60	110	53	57	94	100	110	200	54	69	44	26	38	64
Dibenzofuran	97	190	66	73	15	170	130	220	77	100	53	38	15	58
1,4-Dichlorobenzene	2 u	13 u	12 u	1 j	2 u	11 u	9 uj	4 u	1 j	14 u	8 u	3 u	3.1	9
Di-n-butylphthalate	590 j	13 u	12 u	12 uj	6 uj	11 u	9 uj	11 uj	79 uj	14 u	18	4 uj	220	1700
Di-n-octylphthalate	2 u	13 u	24 u	26 uj	2 uj	11 u	18 u	22 uj	1 uj	14 u	17 u	7 uj	58	4500
Butylbenzylphthalate	3 uj	13 u	12 u	26 uj	3 uj	11 uj	9 u	22 uj	1 u	500	8 u	16 uj	4.9	64
Bis(2EH)phthalate	52 uj	500	230 uj	32 uj	67 uj	140	62 uj	45 uj	79 uj	160	95	58 uj	47	78
Total PCBs	6	10	7	7 j	6	8	7	6	5	7 j	7	6	12	65

u=Not detected at detection limit shown

j=Estimated concentration

SMS= Sediment Management Standards (WAC 204-173)

SQS= Sediment Quality Standards

CSL= Cleanup Screening Level

=Exceeds Cleanup Screening Level

uj uj=Estimated detection limit

-= -=No sample

Quarter 1= Oct to Dec 1993

Quarter 2= Jan to April 1994

Quarter 3= May to July 1994

Quarter 4= August to Oct 1994

Table 5(cont.): Comparison of semivolatile organics detected in settling particulate matter to Ecology's Sediment Management Standards.

Station	EB6				EB6				EB7				SMS	
Depth	Surface	–	–	–	Bottom	–	–	–	Bottom	–	–	–		
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	SQS	CSL
TOC (%)	–	4.2	7.3	9.8	6.4	4.7	7.1	7.6	7.3	3.8	7.1	7.0		
DRY WEIGHT NORMALIZED CONCENTRATIONS														
Phenol	–	1900 u	860 uj	2600	100 j	110 j	880 u	650 uj	54 j	120 j	920 u	670 uj	420	1200
4-Methylphenol	–	1900 u	860 u	550 uj	130 u	450 u	880 u	14000	130	470 u	920 u	4600	670	670
Pentachlorophenol	–	1900 u	8600 uj	5500 u	660 u	450 u	8800 u	4500 u	620 u	470 u	9200 uj	3500 u	360	690
Benzyl Alcohol	–	1900 u	1700 u	550 u	130 u	450 u	1800 u	450 u	120 u	470 u	1800 u	350 u	57	73
Benzoic Acid	–	76000 uj	3000 j	15000 uj	2200 uj	3400 uj	6700 j	4500 u	2700	2000 uj	4900 j	3100 uj	650	650
ORGANIC CARBON NORMALIZED CONCENTRATIONS														
Sum LPAH	–	520 j	450 j	580	1200	1400	440 j	580	1000	1300	700 j	600	370	780
Sum HPAH	–	1800 j	580 j	900	1900	2000	700 j	960	1900	2400	1300 j	1400	960	5300
2-Methylnaphthalene	–	6 j	26	43	50	49	25	29	44	61	44	24	38	64
Dibenzofuran	–	17 j	41	50	85	110	35	45	71	50	61	44	15	58
1,4-Dichlorobenzene	–	45 u	12 u	6 u	2 u	10 u	12 u	6 u	2 u	12 u	13 u	5 u	3.1	9
Di-n-butylphthalate	–	45 u	12 u	10 uj	52 uj	10 u	12 u	11 uj	3 uj	12 u	14 uj	5 uj	220	1700
Di-n-octylphthalate	–	45 u	23 u	29 uj	2 u	10 u	25 u	30 uj	2 u	12 u	25 u	26 uj	58	4500
Butylbenzylphthalate	–	45 u	12 u	29 uj	2 u	10 u	12 u	30 uj	3	12 u	13 u	26 uj	4.9	64
Bis(2EH)phthalate	–	260	59 uj	36 uj	72	130	45 uj	30 uj	56 uj	130	660 uj	31 uj	47	78
Total PCBs	–	–	–	4 j	6	6	6 j	7	6	–	6 j	7	12	65

u=Not detected at detection limit shown

j=Estimated concentration

SMS= Sediment Management Standards (WAC 204-173)

SQS= Sediment Quality Standards

CSL= Cleanup Screening Level

=Exceeds Cleanup Screening Level

uj=Estimated detection limit

–=No sample

Quarter 1= Oct to Dec 1993

Quarter 2= Jan to April 1994

Quarter 3= May to July 1994

Quarter 4= August to Oct 1994

Table 5(cont.): Comparison of semivolatile organics detected in settling particulate matter to Ecology's sediment management standards.

Station	EB8				EB9				SMS	
Depth	Bottom	–	–	–	Bottom	–	–	–		
Quarter	1	2	3	4	1	2	3	4	SQS	CSL
TOC (%)	8.9	4.5	5.1	4.5	4.2	3.2	4.5	7.7		
DRY WEIGHT NORMALIZED CONCENTRATIONS										
Phenol	5100	240 j	490 uj	210 uj	51 j	570 u	810 uj	450 uj	420	1200
4-Methylphenol	38000	440 u	920	210 uj	520	570 u	810 uj	450 u	670	670
Pentachlorophenol	590 u	440 u	4900 u	2100 u	560 u	570 u	8100 uj	4500 u	360	690
Benzyl Alcohol	120 u	440 u	980 u	210 u	120 u	570 u	1600 u	450 u	57	73
Benzoic Acid	3600	2500 uj	1600 j	5100 uj	1700	570 u	7800 j	6400 uj	650	650
ORGANIC CARBON NORMALIZED CONCENTRATIONS										
Sum LPAH	140	420	200 j	290	160	470 j	290 j	220	370	780
Sum HPAH	260	890	530 j	710	360	1000 j	580 j	420	960	5300
2-Methylnaphthalene	7	16	12	13	10	23	24	17	38	64
Dibenzofuran	10	29	16	21	15	34	24	19	15	58
1,4-Dichlorobenzene	1 u	10 u	10	5 u	3 u	18 u	18 u	6 u	3.1	9
Di-n-butylphthalate	1 u	10 u	10 uj	6 uj	3 uj	18 u	18 u	17 uj	220	1700
Di-n-octylphthalate	1 uj	10 u	19 u	24 uj	3 uj	56 j	36 u	30 uj	58	4500
Butylbenzylphthalate	1 u	10 u	10 u	24 uj	3 uj	18 u	18 u	30 uj	4.9	64
Bis(2EH)phthalate	29 uj	100	3 uj	2000 j	1100 uj	170	19 uj	25 uj	47	78
Total PCBs	8	22 j	9	16	6	9	3 j	6 j	12	65

u=Not detected at detection limit shown
uj=Estimated detection limit
j=Estimated concentration
-=No sample
SMS= Sediment Management Standards (WAC 204-173)
Quarter 1= Oct to Dec 1993
SQS= Sediment Quality Standards
Quarter 2= Jan to April 1994
CSL= Cleanup Screening Level
Quarter 3= May to July 1994
=Exceeds Cleanup Screening Level
Quarter 4= August to Oct 1994

Table 6: Summary of metals and organics detected in settling particulate matter from the central Seattle Waterfront that exceeded Ecology's Sediment Management Standards, Sediment Quality Standards (SQS), WAC 173-204.

Station	Location	Chemical	Total Number of Chemicals
EB1-Surface	West end of Pier 59	Mercury, LPAH, dibenzofuran, bis(2EH)phthalate, pentachlorophenol, benzoic acid, benzyl alcohol	7
EB1-Bottom	-	Mercury, LPAH, HPAH, dibenzofuran, bis(2EH)phthalate, di-n-octyl phthalate, TPCBs, benzyl alcohol, benzoic acid	9
EB2	Between 56/57 @ Head of Slip	Mercury, copper, LPAH, HPAH, 2-methylnapthalene, dibenzofuran, 1,4-dichlorobenzene, bis(2EH)phthalate, phenol, 4-methylphenol, butyl benzyl phthalate, pentachlorophenol, benzoic acid	13
EB3	Between 56/57 @ Mouth of Slip	Mercury, LPAH, HPAH, 2-methylnapthalene, dibenzofuran, di-n-butyl phthalate, bis(2EH)phthalate, pentachlorophenol, 4-methylphenol, benzyl alcohol, benzoic acid	11
EB4	Under Pier 56	Mercury, LPAH, HPAH, 2-methylnapthalate, dibenzofuran, bis(2EH)phthalate, 4-methylphenol, pentachlorophenol, benzoic acid	9
EB5	Between 54/55	Mercury, LPAH, HPAH, 2-methylnapthalene, dibenzofuran, butyl benzyl phthalate, bis (2EH)phthalate, 4-methylphenol, pentachlorophenol, benzoic acid	10
EB6-Surface	West end Pier 54	Mercury, chromium, LPAH, HPAH, 2-methylnapthalene, dibenzofuran, bis(2EH)phthalate, phenol, benzoic acid	8
EB6-Bottom	-	Mercury, LPAH, HPAH, 2-methylnapthalene, dibenzofuran, bis(2EH)phthalate, 4-methyl phenol, benzoic acid	8
EB7	Adjacent to Fire Boat Dock	Mercury, LPAH, HPAH, 2-methylnapthalene, dibenzofuran, bis(2EH)phthalate, 4-methyl phenol, benzoic acid	8
EB8	South of Passenger Ferry	Mercury, LPAH, dibenzofuran, 1,4-dichlorobenzene, bis(2EH)phthalate, TPCBs, phenol, 4-methylphenol, benzoic acid	9
EB9	Southwest Corner Pier 48	Mercury, LPAH, HPAH, dibenzofuran, bis(2EH)phthalate, benzoic acid	6

chemical = Also exceeds cleanup screening level

Table 7: Summary of metals and organics exceeding Ecology's Sediment Management Standards (Cleanup Screening Levels) in settling particulate matter from Elliott Bay.

Chemical	Samples*	Percent Exceeding	Location of Highest
Mercury	36/44	84%	EB-2
Benzoic Acid	19/41	46%	EB-2
LPAH	15/41	37%	EB-3
Dibenzofuran	14/41	34%	EB-4
Bis(2-ethyl hexyl) phthalate	13/41	32%	EB-8
4-Methylphenol	8/41	20%	EB-8
2-Methylnapthalene	6/41	15%	EB-4
Pentachlorophenol	5/41	12%	EB-1S
Phenol	3/41	7%	EB-8
Benzyl Alcohol	3/41	7%	EB-1B
1,4-Dichlorobenzene	1/41	2%	EB-8
Butylbenzylphthalate	1/41	2%	EB-5
Di-n-butylphthalate	1/41	2%	EB-3
Chromium	1/44	2%	EB-6S
Copper	1/44	2%	EB-2

*Samples=Number exceeding standards/total samples collected

Ecology Sediment Standards WAC 173-204, Cleanup screening levels

and 57. The lowest number of exceedences of the CSL were typically observed in surface trap samples.

The distribution of mercury in SPM along the Seattle Waterfront is shown in Figure 6. Mercury was above the CSL in 84% of the samples analyzed indicating it is at problem levels throughout the study area. The only station where mercury did not exceed the CSL during the monitoring period was in the surface samples near the Seattle Aquarium (EB1). The average mercury concentration in SPM during the course of the study was 0.96 mg/kg dry, which is approximately 1.5 times higher than the CSL.

Figure 7 compares concentrations of LPAH, HPAH, Dibenzofuran, and Total PCBs in SPM to the SQS and CSL. Examination of these data indicates that the majority of SPM samples exceeded the SQS for LPAH (76%), HPAH (59%), and dibenzofuran (85%). The SQS for PCBs was exceeded in 10% of samples. In contrast to mercury, substantially fewer exceedences of the CSL were observed for these compounds. Of the four organics shown only LPAH (46%) and dibenzofuran (34%) were measured above the CSL.

Gross Sedimentation Rates

Sediment accumulation rates for the central Seattle Waterfront determined from sediment trap data are shown in Table 8. Two types of accumulation rates are listed. Mass accumulation ($g/cm^2/yr$) is the measured sediment flux into the traps, and accumulation rate (cm/yr) is calculated to represent the actual thickness of new sediment once the particulates have consolidated on the bottom. Both these values should be viewed as estimates of gross sedimentation (i.e., net sedimentation + resuspension). Calculations used to generate the reported sedimentation rates are shown below:

- Mass Accumulation ($g/cm^2/yr$)= [(P/A)/D] x Y
  - P= Amount of material collected (dry grams)
  - A= Collection area of cylinder (cm^2)
  - D= Number of days sediment trap was deployed
  - Y= Number of days in a year (365)

- Accumulation Rate (cm/yr)= Mass accumulation ($g/cm^2/yr$)/Dry density (g/cm^3)
  - Dry density= [Wet density x (Bottom Sediment % solids/100)]
  - Wet density= Estimated from Puget Sound Density Model using % solids data from in-situ bottom sediments (Crecelius, 1989)

Mass accumulation rates for bottom traps along the waterfront, on a dry weight basis, ranged from 0.3-1.8 $g/cm^2/yr$ with a mean of 0.8±0.17 $g/cm^2/yr$. Based on means, the highest mass accumulation rates were consistently measured immediately south of the ferry terminal at station EB-8. A comparison of mass accumulation rates in surface and bottom traps is presented in

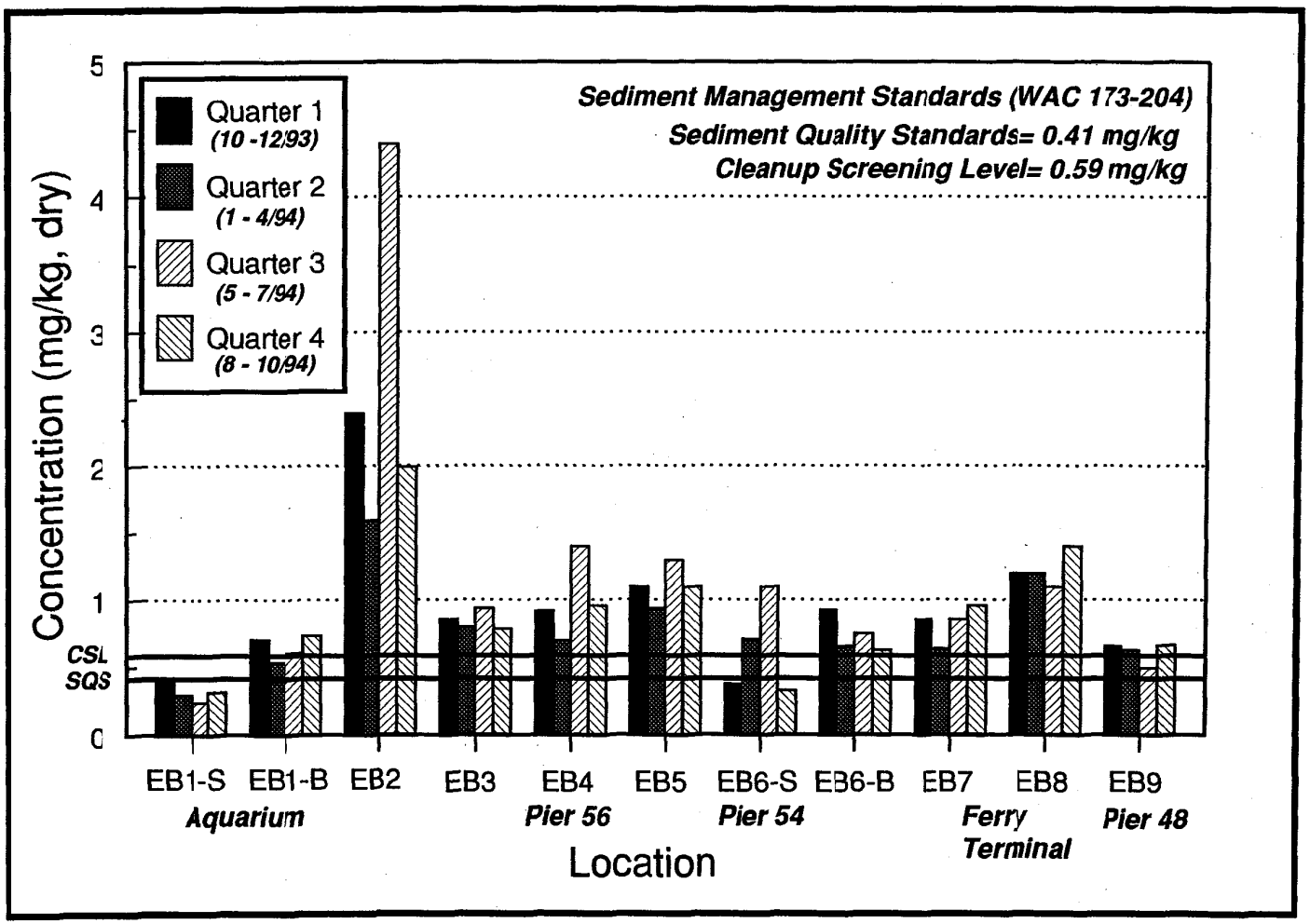
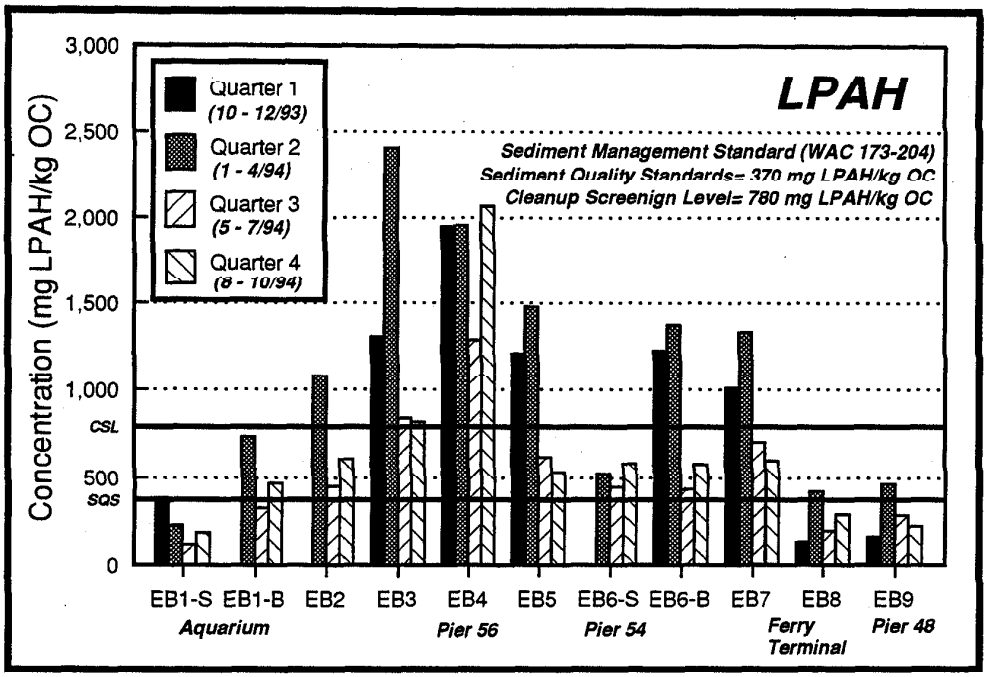


Figure 6: Mercury concentrations in settling particulate matter from the central Seattle Waterfront, October 1993 to October 1994.



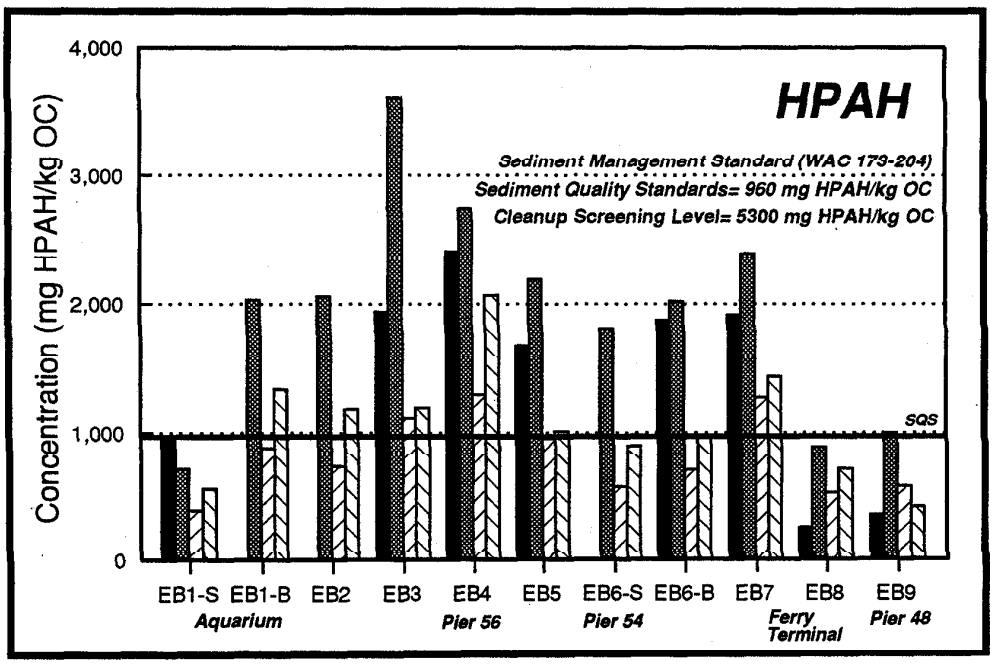
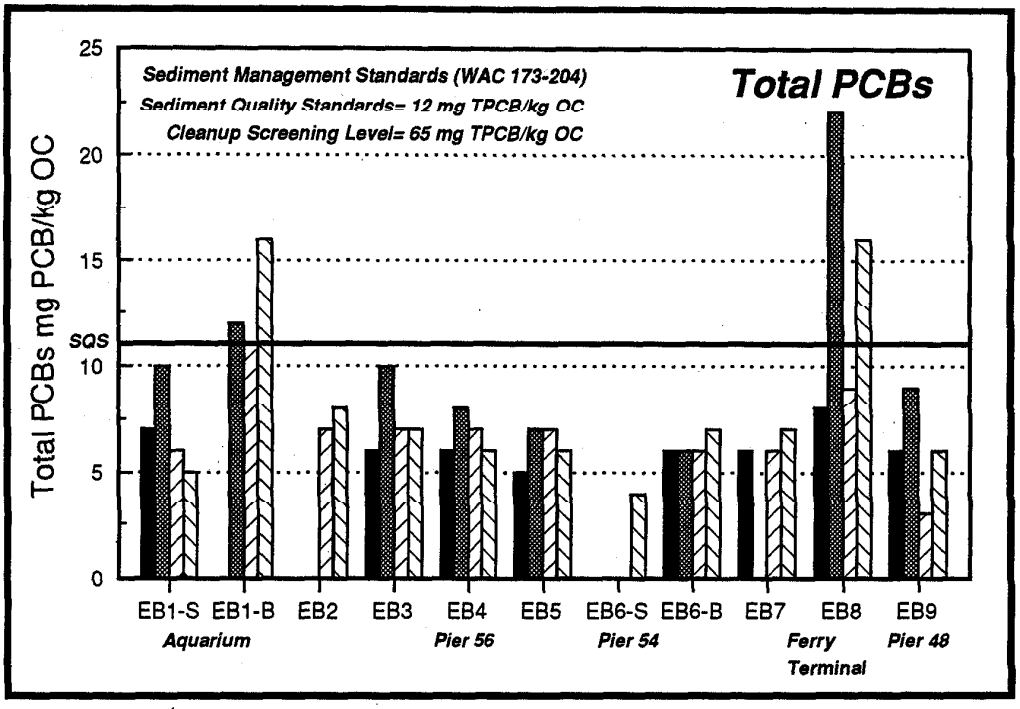


Figure 7: Comparison of Selected Organics in SPM to to Ecology's Sediment Management Standards.



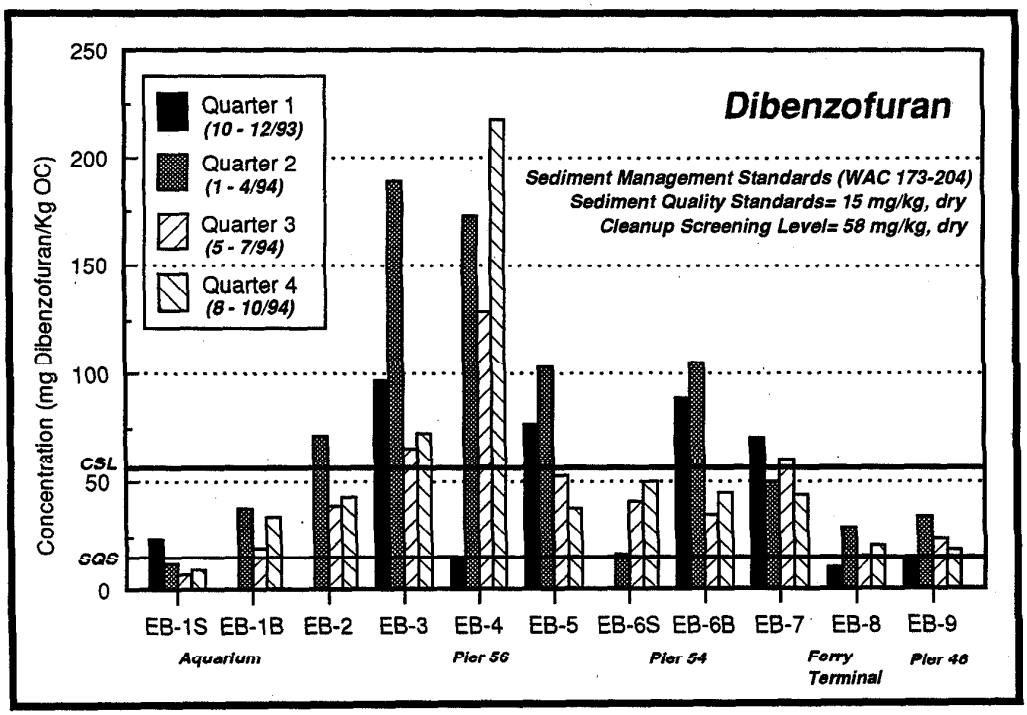


Figure 7(cont.): Comparison of Selected Organics in SPM to Ecology's Sediment Management Standards.

Table 8: Gross sedimentation rates for the central Seattle Waterfront from sediment trap data collected October 1993 to October 1994.

			Mass Accumulation (g/cm2/yr)		Accumulation Rate (cm/yr)	
Station	Quarter	N	Mean	Range	Mean	Range
EB1-S	1	4	0.5	0.4-0.5	1.0	0.9-1.2
	2	4	0.5	0.4-0.6	1.1	0.9-1.3
	3	3	0.6	0.6-0.7	1.3	1.2-1.5
	4	4	0.7	0.5-0.8	1.4	1.1-1.7
EB1-B	1	4	0.4	0.4-0.5	0.8	0.6-1.5
	2	4	0.6	0.5-0.7	1.3	1.0-1.5
	3	4	0.6	0.5-0.6	1.2	1.1-1.2
	4	2	0.5	0.5	1.1	1.1
EB2	1	1	-	0.4	-	0.5
	2	4	0.5	0.5	0.7	0.6-0.7
	3	4	1.1	0.9-1.2	1.2	1.2-1.4
	4	4	1.0	0.9-1.1	1.2	1.1-1.3
EB3	1	4	0.6	0.5-0.7	1.3	1.1-1.5
	2	3	0.6	0.6-0.7	1.5	1.4-1.6
	3	4	1.2	1.0-1.4	2.7	2.2-3.1
	4	4	1.0	0.9-1.1	2.4	2.1-2.6
EB4	1	4	0.6	0.5-0.6	1.8	1.6-1.9
	2	3	0.7	0.7	2.1	2.1-2.2
	3	4	1.1	1.1	3.4	3.3-3.4
	4	4	1.2	1.2-1.3	3.8	3.6-4.0
EB5	1	4	0.6	0.5-0.7	1.4	1.2-1.5
	2	4	0.6	0.6	1.3	1.3
	3	4	1.0	0.9-1.1	2.3	2.0-2.5
	4	4	0.9	0.8-1.0	2.2	1.9-2.3
EB6-S	1	1	-	0.1	-	0.2
	2	2	0.2	0.2	0.3	0.3
	3	3	0.7	0.6-0.7	0.9	0.8-1.0
	4	4	0.7	0.6-0.7	0.8	0.7-0.9
EB6-B	1	4	0.4	0.4	0.5	0.5
	2	4	0.4	0.3-0.5	0.5	0.3-0.6
	3	4	0.7	0.6-0.9	0.9	0.8-1.2
	4	4	0.7	0.6-0.8	0.9	0.8-1.0
EB7	1	4	0.6	0.5-0.6	1.8	1.6-1.9
	2	2	0.6	0.6	2.1	2.1-2.2
	3	4	0.8	0.7-0.8	2.6	2.5-2.7
	4	3	0.7	0.6-0.8	2.6	2.2-2.9
EB8	1	4	0.8	0.6-1.0	1.5	1.1-1.8
	2	4	0.6	0.5-0.7	1.0	0.8-1.2
	3	4	1.7	1.5-1.8	3.0	2.9-3.2
	4	4	1.5	1.4-1.6	2.7	2.5-2.9
EB9	1	3	0.5	0.5	0.6	0.6
	2	4	0.4	0.4	0.5	0.5
	3	4	0.6	0.6	0.8	0.7-0.8
	4	4	0.6	0.5-0.6	0.7	0.7
Overall	Surface	25	0.6	0.1-0.8	1.0	0.3-1.4
	Bottom	133	0.8	0.3-1.8	1.6	0.3-4.0

Quarter 1= Oct - Dec 93;Quarter 2= Jan - April 94

Quarter 3= May - July 94; Quarter 4= August - Oct 94

Figure 8. Surface rates were usually equal to or less than corresponding bottom rates. During the third and fourth quarters of monitoring the station at the west end of Pier 54 showed similar rates throughout the water column. No consistent pattern was observed in rates near Pier 59. Predicted accumulation rates on the bottom from bottom trap data ranged from 0.3 to 4.0 cm/yr with a mean of 1.6±0.88 cm/yr.

Gross accumulation rates from bottom trap data (3' above the bottom) are compared in Figure 9. Several patterns are evident in these data. The highest rates were typically measured during the third (May to July) and fourth (August to October) quarters of monitoring. Rates measured near Pier 59 and the west end of Pier 48 were fairly consistent and on the lower end of rates measured during the course of the study. At the remaining stations rates were seasonally variable, especially immediately south of the ferry terminal (EB8).

In general, areas with the most variable rates (Pier 56/57 and south of the Ferry Terminal) tended to correspond to locations that also had the highest amount of vessel traffic (see Figure 9). Conversely, areas which are least influenced by vessel traffic (near the Seattle Aquarium and the southwest end of Pier 48) did not exhibit the same degree of seasonal fluctuations in gross sedimentation rates that was observed at these other locations. The spatial and temporal patterns observed in gross sedimentation rates along the waterfront seem to suggest that vessel movements are affecting gross sedimentation by locally resuspending bottom sediments.

Vessel traffic along the central Seattle waterfront usually peaks during the summer tourist season (May through September). Some examples of tourist associated vessel traffic along the waterfront includes: harbor tours (operating out of both Pier 55 and Pier 57), fishing charters (Pier 54) and large vessels such as the Canadian Ferry "Royal Victorian" which makes daily runs to the north side of Pier 48 typically between May and September.

Results of ^{210}Pb analysis of the trap material also seem to support the idea that vessel movements are affecting gross sedimentation rates by locally resuspending bottom sediments. ^{210}Pb levels in bottom traps, shown in Figure 10, were at a minimum during the third quarter (May to July) of monitoring (Unfortunately, ^{210}Pb activities in the trap material was not determined during the fourth quarter of monitoring). During episodes when bottom sediments are being resuspended into the water column, ^{210}Pb activities in SPM near the bottom would be expected to drop because water column particulates which typically have higher ^{210}Pb activities are being mixing with lower activity bottom sediments suspended in the water column.

The data collected implies that vessel movements are playing an important role in resuspending bottom sediments along the central Seattle Waterfront, especially during the summer and early fall. Other widespread factors such as seasonal variations in plankton populations and discharge from the Duwamish River may also contribute to the increased sedimentation observed during the summer. However, the apparent connection between the amount of gross sedimentation and the level of vessel activity in the area points more toward vessels as the major factor controlling

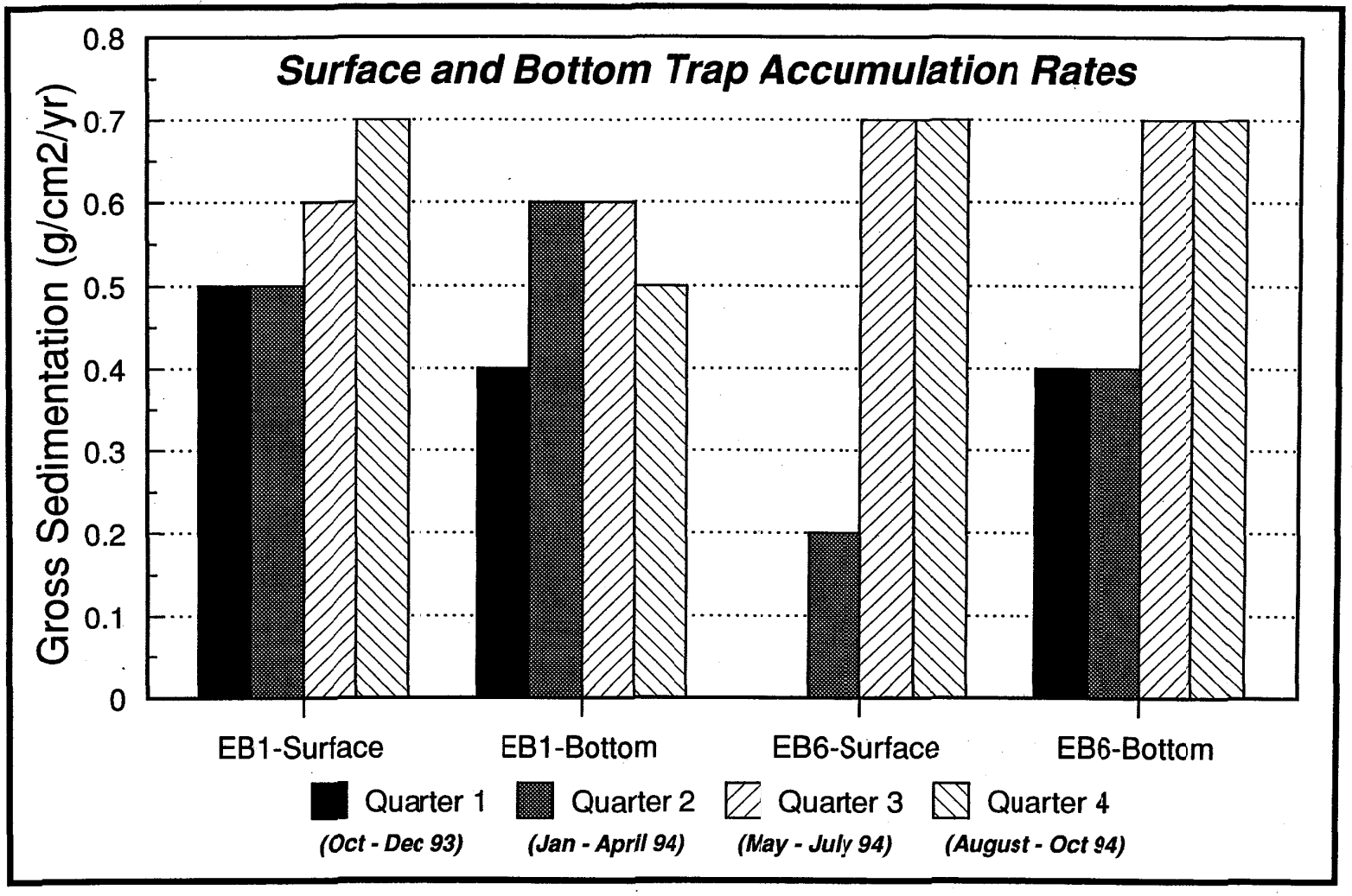


Figure 8: Comparison of sediment accumulation rates in surface and bottom traps.

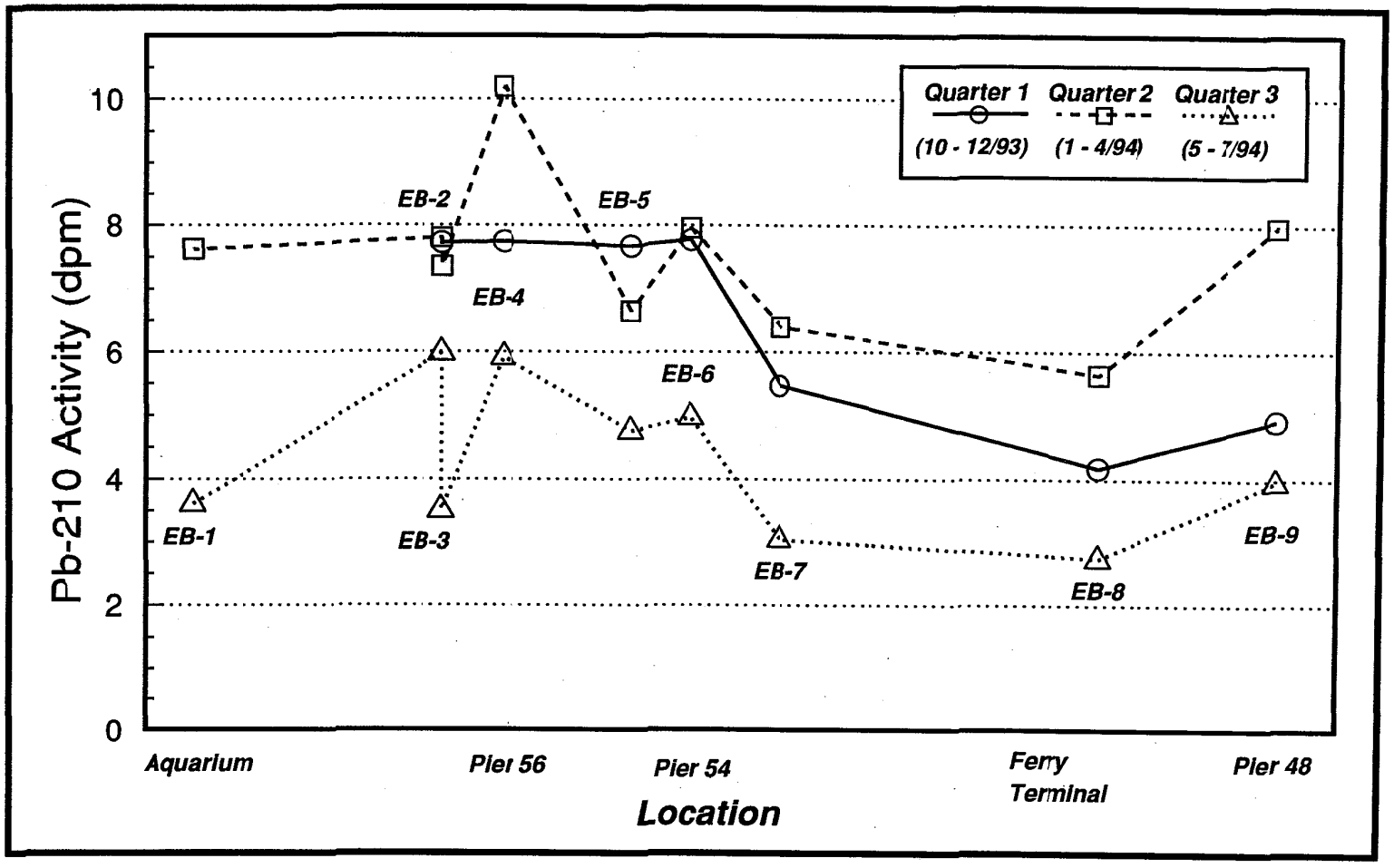


Figure 10: Comparison of Pb-210 levels in bottom traps from the central Seattle Waterfront between October 93 and July 94.

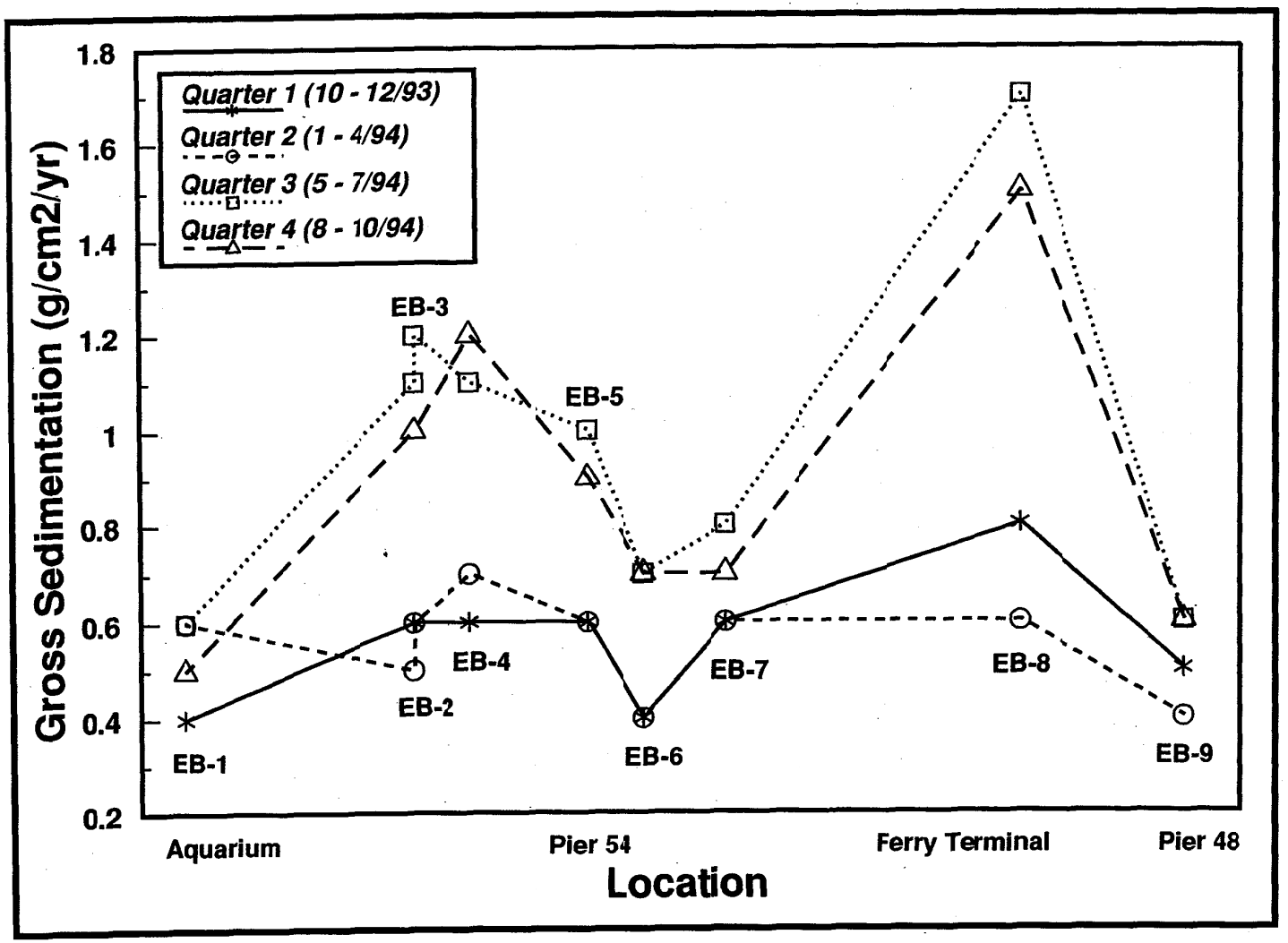


Figure 9: Comparison of gross sedimentation rates from sediment traps located 3 feet above the bottom along the central Seattle Waterfront.

resuspension. Vessel traffic and its effects on resuspension of bottom sediments is discussed in more detail in Volume II.

Bottom Sediment

Nearshore Grain Size Mapping

The percent fines (<0.62um) content of bottom sediments (top 2 cm) in the study area is contoured in Figure 11. Examination of these data indicates that the majority of samples collected during the grain size mapping survey contained <50% fines. Areas immediately adjacent to the bulkhead line contained very little fine material. In addition, two sediment capping projects have also occurred in the last 6 years which have altered the grain size distribution of sediments in the area. These projects include the Ferry Terminal Cap which placed 10,000 yds^3 of material over 4 acres in 1989 and the Pier 53-55 cap which involved 20,000 yds^3 of material over 4.5 acres in 1992 (Romberg, 1995). Both projects used clean sand as a capping material.

Several localized areas were present that contained greater than 60% fines. The largest area is located between Piers 48 and 52. This area roughly corresponds to one of the current gyres previous discussed under net current circulation.

Deep Cores

Three cores were collected in June 1994 to evaluate net sedimentation rates using ^{210}Pb profiles and ^{137}Cs dating as a cross-check. Selected chemical analyses were also performed on these cores to evaluate subsurface contaminant profiles.

Net accumulation rates using ^{210}Pb profiles were calculated using two separate models (Boatman, 1995). The first, which has been used at a number of locations in Puget Sound is a simple burial and decay model which assumes a constant rate of supply of excess ^{210}Pb to the surface sediments (Krishnaswamy, et al, 1971). No evidence of a defined surface mixed layer was observed in any of the cores collected using the burial and decay model. Possible explanations for the lack of a sediment mixed layer could include; the presence of high chemical concentrations and/or more likely periodic disturbance of the surface sediments which prevents the establishment of a burrowing benthic community. Given the atypical nature of the profiles obtained with the burial and decay model, the data were also analyzed with a compaction/decay model. This model is based on a one-dimensional advection-diffusion equation, which considers sedimentation and compaction (Christensen, 1982).

Sedimentation rates for the waterfront determined from these models ranged from 0.1 - 0.72 $g/cm^2/yr$, with a mean of 0.28±0.26 $g/cm^2/yr$. In cores C1 (Between Pier 54 and 55) and C3 (North of Pier 48) rates from both models were in relatively good agreement, yielding net accumulation rates of 0.20±0.89 $g/cm^2/yr$ (C1) and 0.11±0.11 $g/cm^2/yr$ (C3), at each location

Figure 11: Bottom sediment percent fines contours for the Elliott Bay Waterfront Recontamination study area.

respectively. ^{137}Cs dating is also in good agreement with the assigned dates from ^{210}Pb profiles in core C1. No ^{137}Cs activity was noted in core C3, which suggests that the surface sediment layer has been removed from this location, probably through dredging. The average accumulation rate for the waterfront determined during the present study is in good agreement with other data collected in the vicinity of Pier 64/65 which reported a net accumulation rate of 0.26 ± 0.04 g/cm^2/yr (Hart Crowser, 1990).

Core C2 collected between Piers 56 and 57 exhibited a somewhat different accumulation pattern then the other two locations. Calculated accumulation rates and estimated dates for each section in core C2 are shown below. Dates for each core section were estimated by dividing the difference in depths between the midpoints of adjacent sections by the mean accumulation rate (cm/yr) of the sections. This yields the average total time to accumulate the given thickness between the midpoints of the sections.

Summary of calculated net accumulation rates and estimated dates for core C2

Model Type	Depth (cm)*	Estimated Date	Accumulation Rate (g/cm^2/yr)
^{210}Pb Burial and Decay	2.8	1986	0.72
" "	13	1976	0.30
" "	23	1962	0.26
" "	34	1930	0.09
" "	45	1900	0.08
Compaction and Decay	66	1820	0.06
" "	87	1770	0.11
" "	110	1710	0.10
" "	130	1660	0.10
" "	150	1590	0.10
" "	170	1530	0.11
" "	190	1450	0.11
" "	210	1410	0.09

* Depth= Midpoint of section corrected for compaction

These data indicate that net sedimentation has been fairly constant up to as recent as 1962 (0.10 g/cm^2/yr) at this location. Since 1962, the accumulation rate has been increasing (0.28 g/cm^2/yr) with a large recent jump occurring after about the mid-1970s to the present value of 0.72 g/cm^2/yr. The higher rate for this location seems to be consistent with grain size information that suggests net deposition is occurring based on the presence of poorly sorted fine grained material (Boatman, 1995).

The results of chemical analysis of bottom cores from the central Seattle Waterfront are summarized in Table 9. Surface sediments (top 10 cm) from all cores were composed of primarily silt and clay size particles and which had relatively high TOC levels (7.0 to 7.7%). In general, cores from the northern portion of the study (C1 and C2) exhibited vertical contaminant profiles with peak concentrations occurring at depth. In contrast, maximum concentrations for most chemicals in core C3 (north of Pier 48) occurred in the top 7 cm of the core. The contaminant profile for core C3 is consistent with ^{137}Cs results that suggested the upper portion of the sediment record may have been removed.

Relatively high concentrations of mercury were present in all cores. This was especially true between Pier 56 and 57 (C2), where concentrations as high as 16 mg/kg occurred at a depth of 105-168 cm. Lead concentrations in the upper 7 cm of core C3 (north of Pier 48) was extremely high at 2100 mg/kg. This value is roughly 3.5 times higher then the next highest lead concentration measured during the present survey.

Vertical profiles of PCBs showed a similar pattern to metals. Cores from the northern portion of the study area had subsurface maximums, while the highest concentrations south of the ferry terminal were present in the upper 7 cm of the core. The highest Total PCB levels (8800 ug/kg, dry) were measured in the 21-42 cm layer of core C2 (between Pier 56 and 57). Dating information suggest that this layer was deposited sometime between the early 1900's and the early 1960's. PCBs were first commercially produced in 1929. Since that time they were widely used in industrial applications including: insulating fluids, plasticizers, in inks and carbonless paper, and as heat transfer and hydraulic fluids. Their manufacture was restricted by EPA in 1977 and banned in 1979 (Ecology, 1995).

Comparison to Sediment Management Standards

Individual contaminants in bottom cores are compared to the SMS in Table 9. Vertical profiles of copper, lead, mercury, and zinc are displayed in Figure 12. Similar patterns were observed for all of these metals in the sediment records. The highest concentrations occurred at depth, usually within the top 100 cm. One exception to this pattern was core C3 located north of Pier 48, which typically had the highest metals at the surface with concentrations declining with depth. This was especially true for lead which was exceptionally high (2100 mg/kg) in the top 3 cm. Concentration peaks for copper, lead, mercury and zinc between Piers 56 and 57, and lead and

Table 9: Comparison of metals and organics in bottom cores to Ecology's Sediment Management Standards.

Sample* Interval (cm)	%Solids	TOC (%)	Grain Size Sand (>62.5um)	Silt (62.5-4um)	Clay (<4um)	Total Metals (mg/kg, dry) Cu	Pb	Ag	Hg	Zn	Al	Fe	Mn	PCBs (ug/kg, dry) 1242	1254	1260	Total	Total PCBs*
Core #: C1 (Between Piers 54 and 55)																		
0-8	25	7.7	13	51	36	210	260 j	4.5	2.2	380 j	20000	31000	230	340 j	760	580	1700 j	8 j
8-16	31	-	-	-	-	280	330 j	4.7	2.5	420 j	23000	33000	270	230 j	1300	750	2300 j	10 j
16-32	33	-	-	-	-	290	480 j	3.7	5.5	590 j	22000	29000	230	500 j	2900	1480	4900 j	19 j
32-80	39	-	-	-	-	270	580 j	4.9	5.1	530 j	21000	27000	220	220 j	560	480	1300 j	6 j
80-128	44	-	-	-	-	180	510 j	5.1	3.4	400 j	22000	29000	250	100 u	100 u	100 u	100 u	-
128-140	49	-	-	-	-	90	280 j	0.9 j	2.9	280 j	25000	28000	300	79 u	79 u	79 u	79 u	-
Core #: C2 (Between Piers 56 and 57)																		
0-11	24	7.0	10	49	41	340	430 j	4.4	5.3	590 j	26000	30000	260	370 j	1900	2100	4400 j	30 j
11-21	27	-	-	-	-	300	540 j	3.8	7.0	710 j	24000	28000	240	680 j	2500	1300	4500 j	19 j
21-42	23	-	-	-	-	690	590 j	1.4 j	9.6	1000 j	46000	34000	210	1500 j	5500	1800	8800 j	26 j
42-105	21	-	-	-	-	300	400 j	6.2	12	1200 j	8500	13000	76	1400 j	4300	1100	5800 j	16 j
105-168	25	-	-	-	-	360	470 j	5.2	16	950 j	10000	20000	100	990 j	2700	1000	4700 j	14 j
168-206	29	-	-	-	-	1100	490 j	3.8	11	1700 j	11000	20000	130	300 j	150	580	1000 j	8 j
Core #: C3 (North of Pier 48)																		
0-7	58	7.3	34	46	20	160	2100 j	3.3	1.8	340 j	19000	28000	220	100 j	560	330	990 j	5 j
7-13	63	-	-	-	-	76	250 j	1.2 j	1.1	140 j	12000	32000	210	67 uj	56 j	47 j	100 j	1 j
13-26	62	-	-	-	-	68	140 j	0.53 j	1.2	110 j	11000	21000	160	71 u	71 u	71 u	71 u	-
26-65	65	-	-	-	-	45	290 j	0.3 u	0.82	230 j	13000	17000	140	56 u	56 u	56 u	56 u	-
65-117	68	-	-	-	-	24	7.4 j	0.3 u	0.054 j	34 j	12000	15000	120	44 u	44 u	44 u	44 u	-
117-143	68	-	-	-	-	23	6.3 j	0.3 u	0.038 j	29 j	8700	12000	110	62 u	62 u	62 u	62 u	-
143-172	66	-	-	-	-	24	4.8 j	0.3 u	0.036 j	34 j	9500	13000	110	58 u	58 u	58 u	58 u	-
172-199	65	-	-	-	-	30	4.8 j	2.9 j	0.052 j	35 j	10000	14000	120	72 u	72 u	72 u	72 u	-
SMS-Sediment Quality Standards						390	450	6.1	0.41	410	-	-	-	-	-	-	-	12*
SMS-Cleanup Screening Level						390	530	6.1	0.59	960	-	-	-	-	-	-	-	65*

Sample Interval= Depths corrected for core compaction

SMS= Ecology Sediment Management Standards (WAC-173-204)

*=Organic carbon normalized basis

=Exceeds Cleanup Screening Level

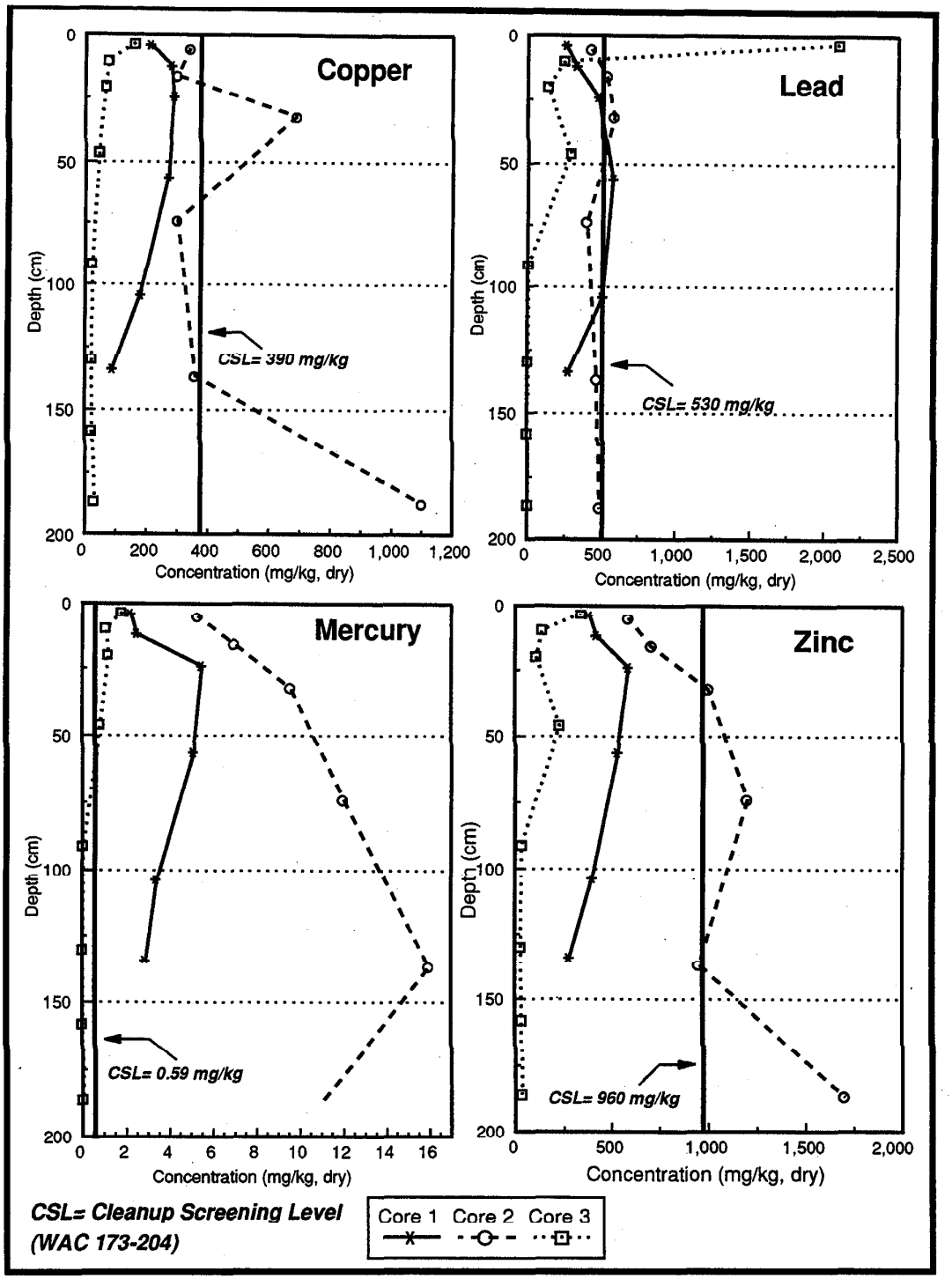


Figure 12: Copper, lead, mercury, and zinc profiles in bottom cores from the central Seattle Waterfront.

mercury between Piers 54 and 55 were above the CSL. Near surface concentrations of lead (top 3 cm) and mercury (top 50 cm) exceeded the at CSLs north of Pier 48.

Total PCB profiles displayed in Figure 13, showed the same general pattern as metals, with the highest concentrations occurring at depth. Again, an exception was noted in core C3 where PCB peaks occurred near the surface. Between Pier 56 and 57 was the only location where PCB levels exceeded the CSL of 65 mgPCB/Kg OC. PCB levels on a organic carbon normalized basis in core C2 reached a maximum of 130 mgPCB/Kg OC.

These data indicate that in the northern portion of the study area between Piers 54 and 57 any sediment cleanup activity involving sediment removal alone (i.e., dredging) would expose sediments with higher contaminant concentrations then currently exist at the surface. In contrast, at the location of core C3 south of the ferry terminal the danger of exposing more highly contaminated material does not appear to be a problem.

Comparison of Gross and Net Sedimentation Rates

To place sedimentation rates for the Seattle Waterfront into perspective, Table 10 summarizes rates reported for other parts of the waterfront and several waterways in Commencement Bay. The mean sedimentation rate of 0.7 g/cm^2/yr for the Seattle Waterfront determined from sediment traps (gross sedimentation) is in good agreement with the rate reported from the Pier 64/65 study (0.85 g/cm^2/yr). Compared to sediment trap data for Commencement Bay rates along the waterfront are approximately 2-5 times lower. Net sedimentation rates for the waterfront are similar between the present study and the Pier 64/65 study.

Comparison of sedimentation rates from sediment traps (gross sedimentation) and rates from ^{210}Pb dated cores (net sedimentation) have been used in other investigations to estimate bottom sediment resuspension rates (Baker, et al., 1991). Net and gross sedimentation rates from concurrent locations are compared below:

Summary of estimated resuspension rates for the central Seattle Waterfront from sediment trap and bottom core data (g/cm^2/yr)

Location	Gross	Net	Resuspension	Percent
Pier 54 and 55	0.78±0.21	0.20±0.89	0.58±0.91	74%
Pier 56 and 57	0.85±0.28	0.18±0.18	0.67±0.33	79%
Surface only	0.85±0.28	0.72	0.13±0.28	15%
N. of Pier 48	1.2±0.53	0.11±0.11	1.1±0.54	92%

Resuspension= (gross sedimentation - net sedimentation)
Percent= (resuspension/gross sedimentation) * 100

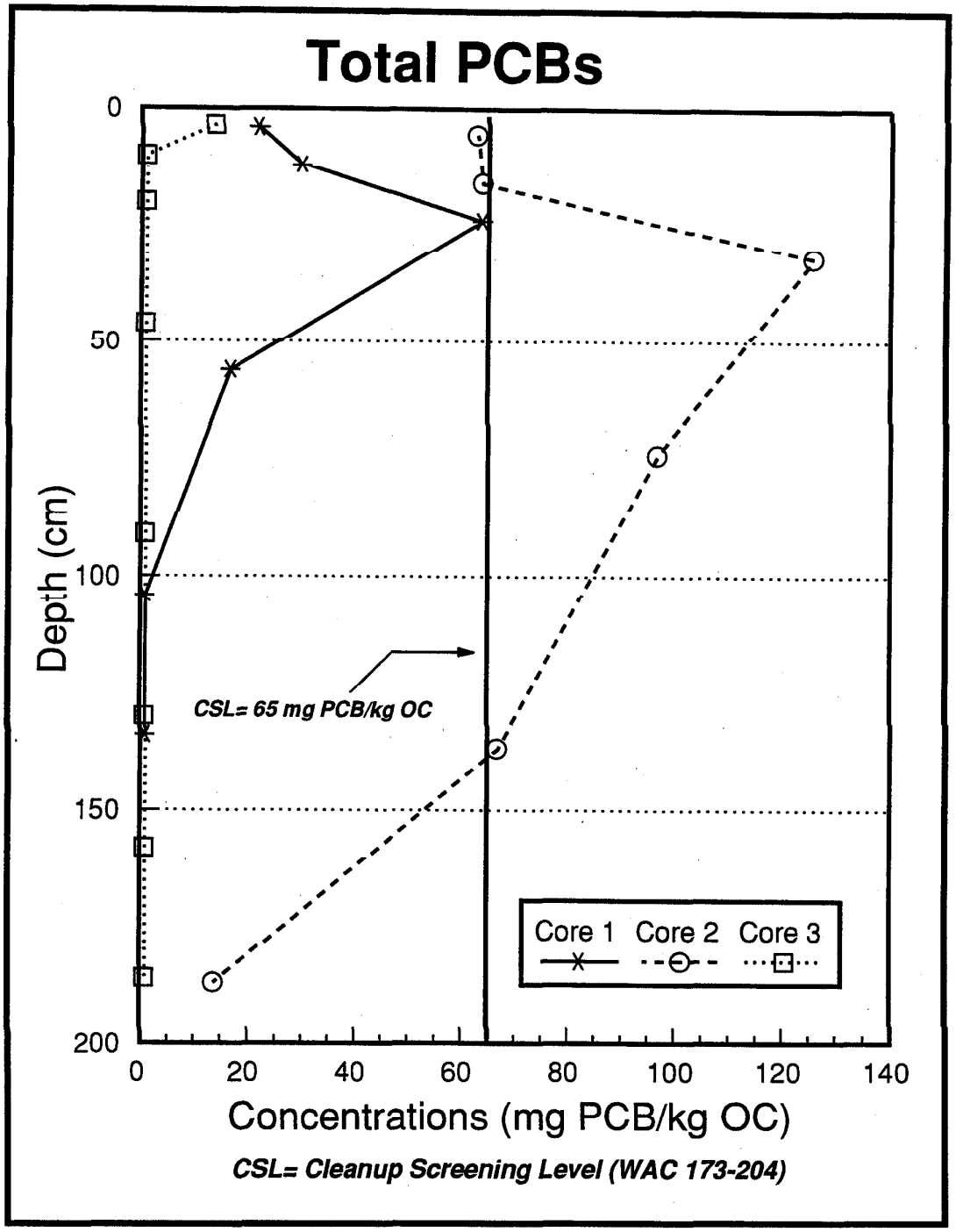


Figure 13: Organic carbon normalized PCB concentrations in bottom cores from the central Seattle Waterfront.

Table 10: Comparison of gross and net sedimentation rates for the central Seattle Waterfront (g/cm2/yr).

Source	Location	Mean ± STD	Range
Gross Sedimentation			
Present Study	Seattle Waterfront	0.7 ± 0.3	0.1 - 1.8
Hart Crowser, 1990	Pier 64/65	0.85 ± 0.01	0.84 - 0.86
Norton, 1993	Thea Foss Waterway	1.7 ± 1.1	0.2 - 5.0
Norton, 1992a,b	Hylebos Waterfront	2.1 ± 0.8	0.7 - 3.8
	Sitcum Waterfront	3.5 ± 1.2	2.1 - 5.7
Net Sedimentation			
Present Study	Seattle Waterfront	0.23 ± 0.26	0.1 - 0.72
Hart Crowser, 1990	Pier 64/65	0.26 ± 0.04	-

Gross rates determined from sediment trap data
Net rates determined from Pb-210 dated cores

Resuspension estimates for the Seattle Waterfront ranged from 0.13±0.28 to 1.1±0.54 g/cm^2/yr, with a mean of 0.62 g/cm^2/yr. These data suggest that as low as 15% (Pier 56/57- using the surface value in core C2 only) to as high as 92% (south of the ferry terminal) of the material collected by the traps in some areas, could be recent bottom sediments which have been resuspended. While the exact proportion of resuspended bottom sediment being collected by the traps is difficult to determine, it is fair to assume that the trapped material is representative of sediments which are mobile in the area.

Sediment resuspension rates for the Seattle Waterfront are similar to resuspension rates reported for Eagle Harbor (0.4 g/cm2/yr) and are somewhat lower than rates reported for other urban embayments in Puget Sound: Bellingham Bay= 3.6; Commencement Bay= 1.0-2.9 g/cm2/yr (Patmont and Crecelius, 1991; Norton, 1993).

As previously discussed a number of factors (net current velocities, spatial and temporal patterns in sediment accumulation and ^{210}Pb activities) suggest vessel activities along the waterfront as the major factor controlling the amount and timing of sediment resuspension. Resuspension and the potential for transport of contaminated sediments would be of the greatest concern in areas where new vessel activities are occurring above or adjacent to contaminated sediments. The design of any sediment remediation project along the Seattle Waterfront should consider vessel activities and their potential to redistribute contaminated sediments to be successful and cost effective over the long-term.

4.0 Conclusions

In general, the spatial distribution of contaminants measured in settling particulate matter (SPM) along the central Seattle Waterfront was in relatively good agreement with previous information on the area. Metals concentrations were fairly low and consistent during monitoring. An exception was mercury which exceeded Ecology's sediment Cleanup Screening Level (CSL) over a large portion of the study area (84% of the samples analyzed were >CSL). The average mercury concentration in SPM during the course of the study was 0.96 mg/kg, dry weight. This concentration is approximately 1.5 times higher than the CSL.

In contrast to metals, organics concentrations were variable both spatially and temporally along the waterfront. Peak concentrations of most organics tended to occur in the northern portion of the study area between Pier 52 (Ferry Terminal) and 57. Concentrations of 18 individual organics exceeded levels in SPM which would be expected to produce some adverse effects on biological resources (the Sediment Quality Standard- SQS). Twelve of these compounds also exceeded the CSLs.

Vertical profiles in bottom cores indicate that in the northern portion of study area (between Pier 52 and 57) concentrations of most contaminants typically peak at depth ranging from 16 to 42 cm. In contrast north of Pier 48 the highest concentrations were present in the top 7 cm. These data indicate that sediment cleanups in the northern portion of the study area that only involved dredging would probably expose more highly contaminated material then currently exists at the surface.

Net current speeds (surface and bottom) were weak along the waterfront being <5.0 cm/sec. The mean net speed for the entire study period was 1.3 cm/sec. Although, net speeds were weak a number of short term spikes were observed in the current records. These maximums ranged from 5.8 to 135 cm/sec. The occurrence of spikes in the records suggests that short term events (on the order of minutes) such as vessel movements are affecting near bottom current speeds.

Overall net current directions tend to be oriented parallel to the faces of piers. A convergent zone which moves water offshore to the west in the vicinity of Pier 52 is also present. This convergent zone located near Pier 52 appears to separate the study area hydrodynamically into a northern and southern region. The observed convergent zone is most likely the result of ferry operations at Pier 52. When docked, the ferries typically apply forward thrust to the stern propellers to hold the vessel in the berth during loading and unloading of cars and passengers. This causes an offshore current to be generated which moves away from Pier 52 to the west.

Gross (net + resuspension) sedimentation rates determined from bottom trap data ranged from 0.3-1.8 g/cm^2/yr with a mean of 0.8±0.17 g/cm^2/yr. Net sedimentation rates for the waterfront

ranged from 0.1 - 0.72 g/cm^2/yr, with a mean of 0.28±0.26g/cm^2/yr. Resuspension estimates for bottom sediments along the Seattle Waterfront ranged from 0.11±0.11 to 1.1±0.54 g/cm^2/yr.

Locations with the most variable gross sedimentation rates tended to corresponded to areas with the highest amount of vessel traffic. These data in conjunction with current velocity measurements and ^{210}Pb results suggest that vessel movements play an important role in resuspending bottom sediments along the central Seattle Waterfront, especially during the summer and early fall.

In general, cores from the northern portion of the study area between Piers 54 and 57 exhibited vertical contaminant profiles with peak concentrations occurring at depth. This was especially true for mercury between Pier 56 and 57, where concentrations as high as 16 mg/kg, dry weight occurred at a depth of 105-168 cm. In contrast, maximum concentrations for most chemicals in a core collected north of Pier 48 occurred in the top 7 cm.

The data collected during the field investigation portion of the waterfront recontamination study is further discussed in Volume II of this report. Particular attention in Volume II is given to implications of the data on sediment remediation strategies for the waterfront area.

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Appendix A - Background information

Literature Search

Sampling and Analysis Plan

Modifications to the Sampling and Analysis Plan

ELLIOTT BAY WATERFRONT RECONTAMINATION STUDY

Literature Search

prepared by

Washington State Department of Ecology
Environmental Investigations and Laboratory Services Program

for

Elliott Bay/Duwamish Restoration Program

July 1993

INTRODUCTION

Recent studies have suggested that recontamination of bottom sediments along the central Seattle Waterfront may occur and could affect the success of sediment remediation projects in this area. As a result, the Elliott Bay/Duwamish Restoration Program Panel decided to conduct a resuspension/recontamination study in order to determine whether it is feasible to undertake sediment remediation projects along the central waterfront.

The first step in designing this study was to conduct a literature search which identifies existing information and ongoing monitoring programs whose data could be used in conjunction with the current study. The results of this review will be used to help design needed field activities for the resuspension/recontamination study to supplement existing information.

For the purposes of this review the outer limit of Elliott Bay was generally taken as a line between Duwamish Head and Smith Cove (Piers 90 and 91). The actual study area was understood to be the nearshore, subtidal Seattle Waterfront from approximately King Street to the north side of Pier 71. This area is shown in Figure A. An attempt was made to compile all sources of information since 1971, using existing figures and tables where possible. Information on the Duwamish River above the mouth and on land-based pollution sources was not included, although some information on these areas will be found among the references cited.

One hundred and four references were found on the subject areas of interest. Subject areas included: currents, distribution of suspended particulates, chemical analysis of suspended particulates, bottom sediment surveys, sediment trap studies, sediment accumulation rates, resuspension, and ongoing monitoring activities. The following pages present a synopsis of the information collected.

TABLE OF CONTENTS

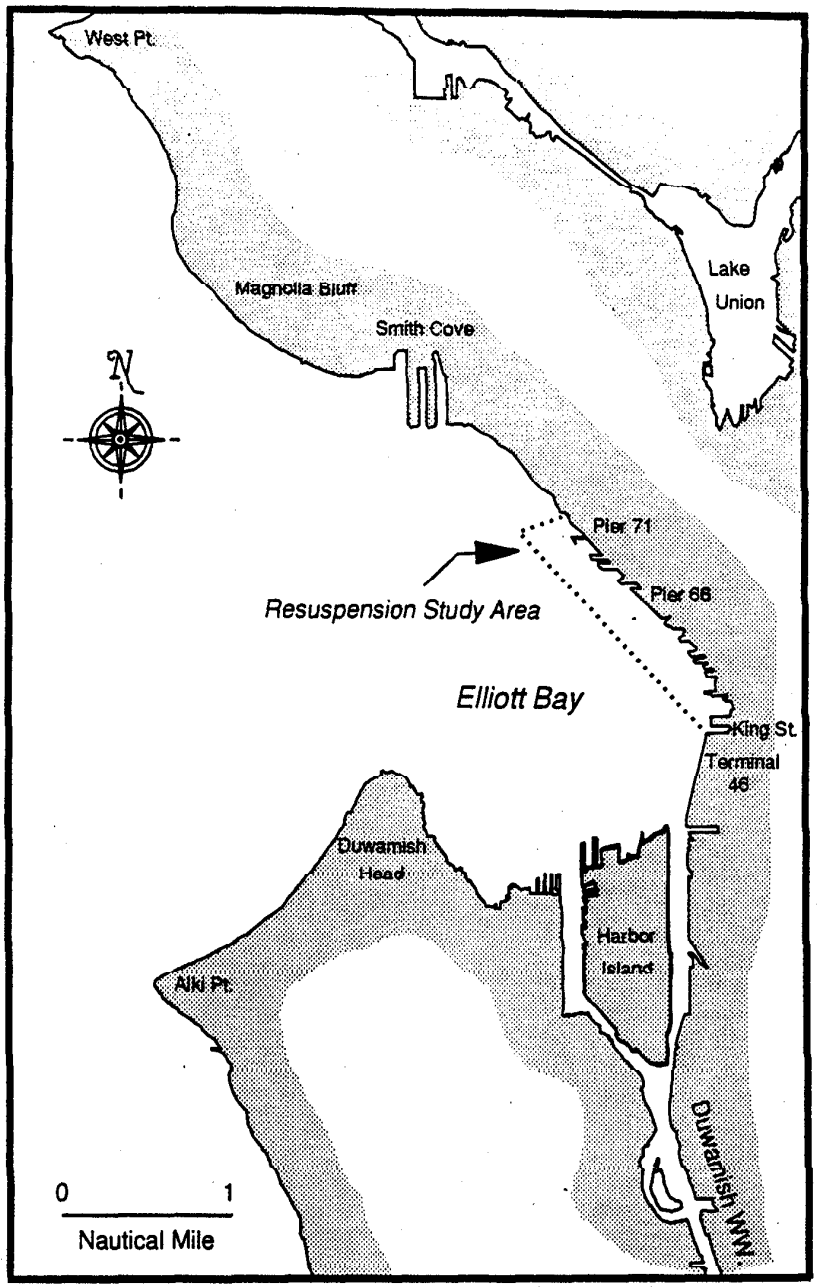


Figure A: Study Area, Elliott Bay Resuspension Study

I. CURRENTS

Most Useful References: 14, 18, 19, 83, 98, 100, 101, 104

Other References: 1, 2, 3, 4, 13, 16, 20, 21, 22, 23, 24, 36, 49, 56, 63, 74, 81, 97

Synopsis of Information Found: Early studies by Rogers (1955) and Winter (1977) using the UW Puget Sound hydraulic model suggested a clock-wise circulation pattern in Elliott Bay, with water generally exiting along Duwamish Head. When conditions of high runoff from the Duwamish River and weak tidal currents were modelled, flow was predominantly to the northwest past Smith Cove.

NOAA (Baker, *et al.*, 1983) conducted field studies during the summer of 1979 and winter of 1980 to describe the currents and hydrography of Elliott Bay for evaluating transport of dissolved and suspended matter. Figure 1 shows locations of current meters and CTD stations used in this study.

Sillcox, *et al.*, (1981) describes NOAA's observations on currents, temperature and salinity during 1979-1980. Findings generally contradicted those from the model. Surveys of temperature and salinity showed the Duwamish River plume was always on the north side of the bay. In both winter and summer most freshwater left the bay to the north. Residence time for water in the inner bay was inferred to be 1-to-10 days depending on depth and season. Winter (1977) calculated residence times of up to 3.5 days for dye moving north along the Seattle waterfront in the Puget Sound model.

Dexter, *et al.*, (1984) concluded the "primary influence of the river discharge is felt in the southern and southeast portions of Elliott Bay and along the Seattle waterfront." Normal seasonal flow of the Duwamish River is depicted in Figure 2 (Santos and Stoner, 1972). Most of the discharge is through the West Waterway. Curl, *et al.*, (1987) compared flows for the Duwamish River with the Denny Way and six other Elliott Bay combined sewer outfalls (CSOs) during eight days of rain between December 31 and January 5, 1986. They found the CSOs were only about 0.4% of river flow.

According to Sillcox, *et al.*, (1981) "Very weak speeds characterized all currents observed in Elliott Bay." Mean speeds were typically less than 5 cm/sec, although occasional instantaneous speeds of 30cm/sec occurred.

Records from current meters deployed in subsequent studies are in line with Sillcox, *et al.'s* conclusions with regard to current speed and direction in Elliott Bay. Chief among these are Dexter, *et al.*, (1984) who made two deployments over a PCB-contaminated dredge disposal site off the Duwamish River; URS Engineers and Evans-Hamilton (1986) who deployed 25 current meters in and around the Duwamish Head area for outfall siting studies for the Renton Sewage Treatment Plant; and 1985-1986 field studies by NOAA (Curl, *et al.*, 1987, 1988) using current meters at a deep-water site south of Pier 91 (site 1 in Figure 1).

Cox, *et al.*, (1984) have summarized Puget Sound current measurements from 1908-1980, including seven sites in Elliott Bay (station #159 - #165). URS Engineers and Evans-Hamilton (1984) synthesized the information from six of these sites to estimate circulation patterns for surface (0 - 50m) and bottom (50m - bottom) waters (Figures 3 and 4).

Three of the current meter sites indexed by Cox, *et al.*, are within the area of interest for the resuspension study. Site #159 in 43 meters of water off the Seattle Waterfront (47 36.7N x 122 21.4W) operated by the National Ocean Survey (unpublished) from March 25-29, 1946, recorded a net surface (2m) speed of 3.99 cm/sec and net direction of 318° true. The other two sites, #160 (Pier 46) and #161 (Pier 15) operated for less than one tidal day, so give no useful information (Patten, 1976).

No other instances of current meter measurements within the resuspension study area were found during the literature search. A draft report by Tomlinson, *et al.*, (1976) contains maps showing movements of dye released at the mouth of the Denny Way CSO.

Conclusion: The circulation pattern of Elliott Bay is well described but nearshore current speed information is generally lacking for the waterfront area.

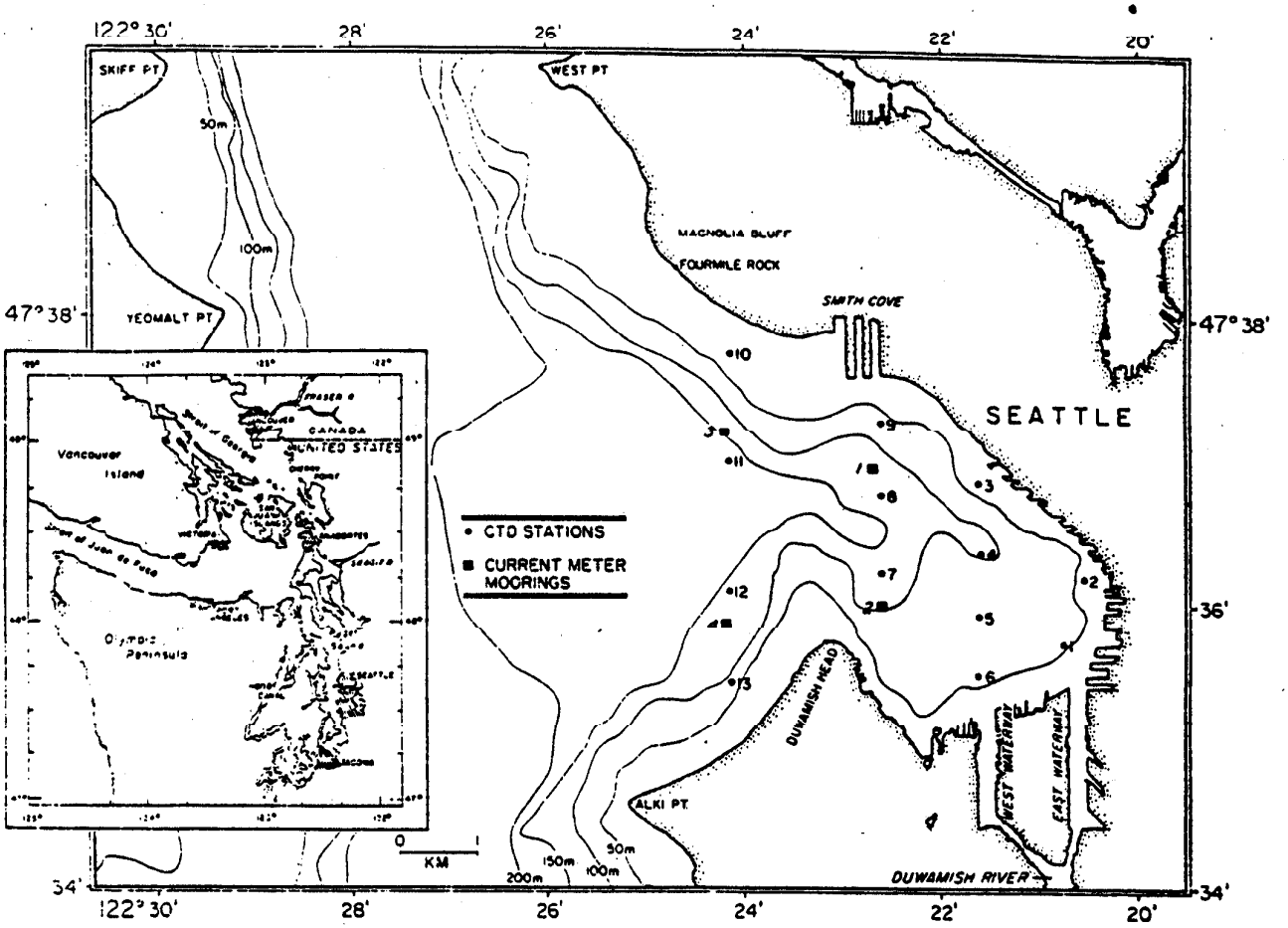
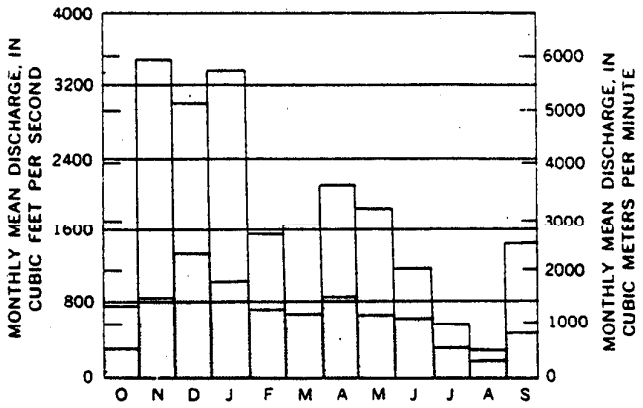
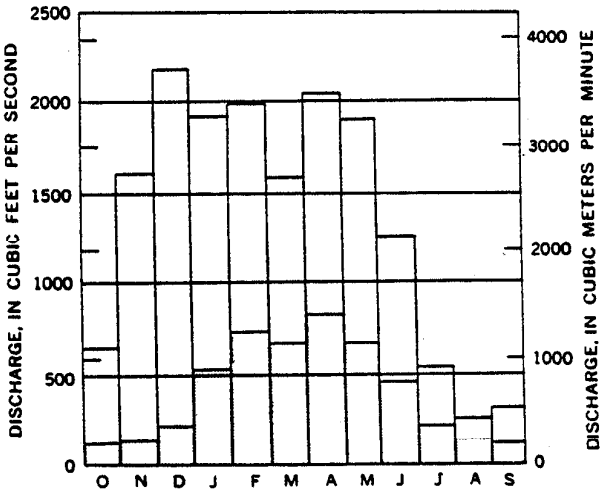


Chart of Elliott Bay showing bathymetry, station locations, mooring locations, and the mouth of the Duwamish River (West Waterway). Contour interval is 50 m.

Figure 1. Baker *et al.* (1983)

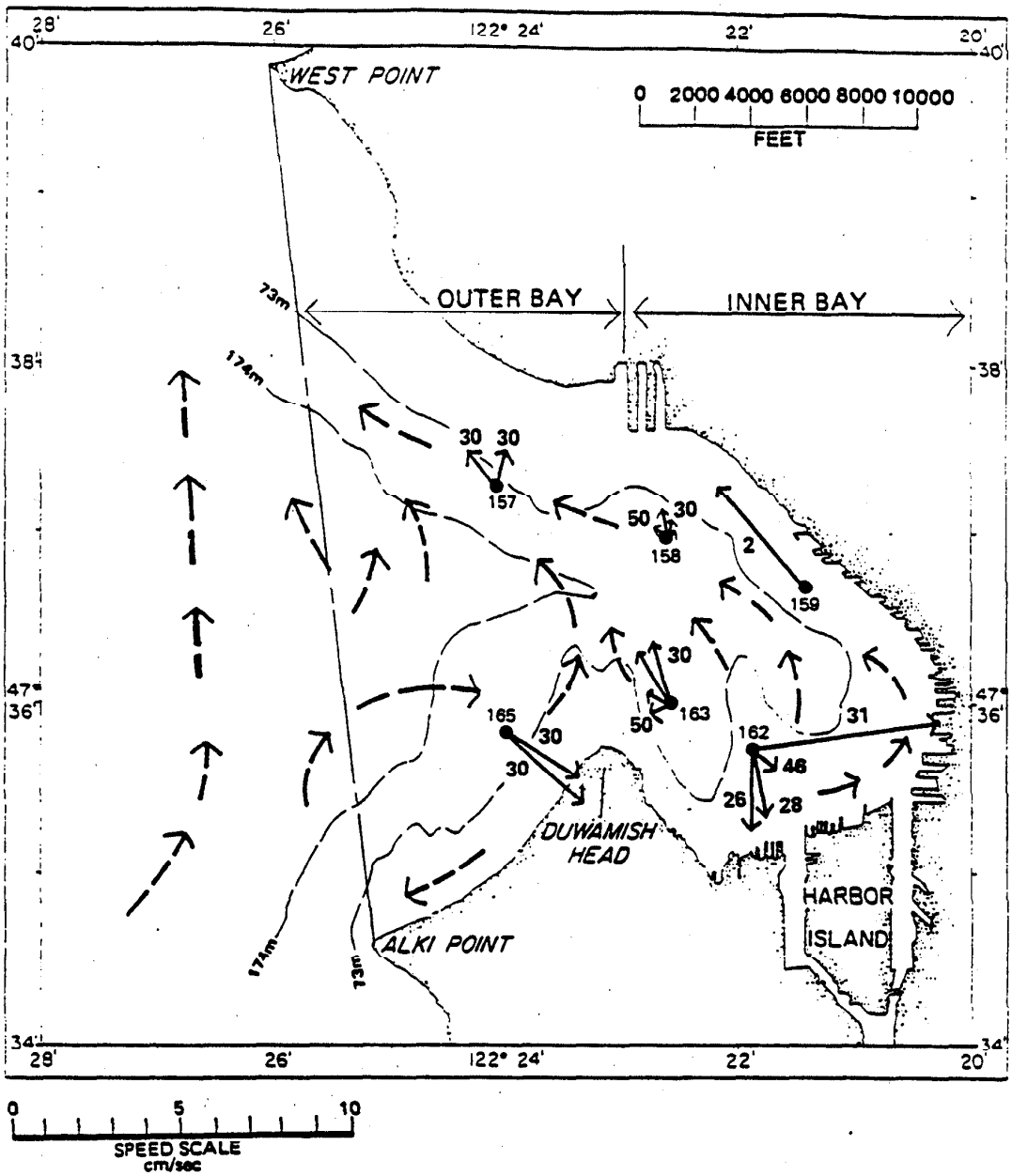


Comparison of monthly mean discharge of the Green River near Auburn for the driest year (1941, shaded bars) and wettest year (1959, shaded plus unshaded bars) during the period 1937–65.



Mean monthly (unshaded plus shaded bars) and minimum monthly (shaded bars) discharges of Green River near Auburn, 1937–65.

Figure 2. Santos and Stoner (1972)



Net velocities (⟶) in Elliott Bay in the depth range of 0 - 50m and inferred circulation patterns (⇢)

Current meter site 158 ●

Current meter depth 30 ⟶
Arrow length proportionate to speed

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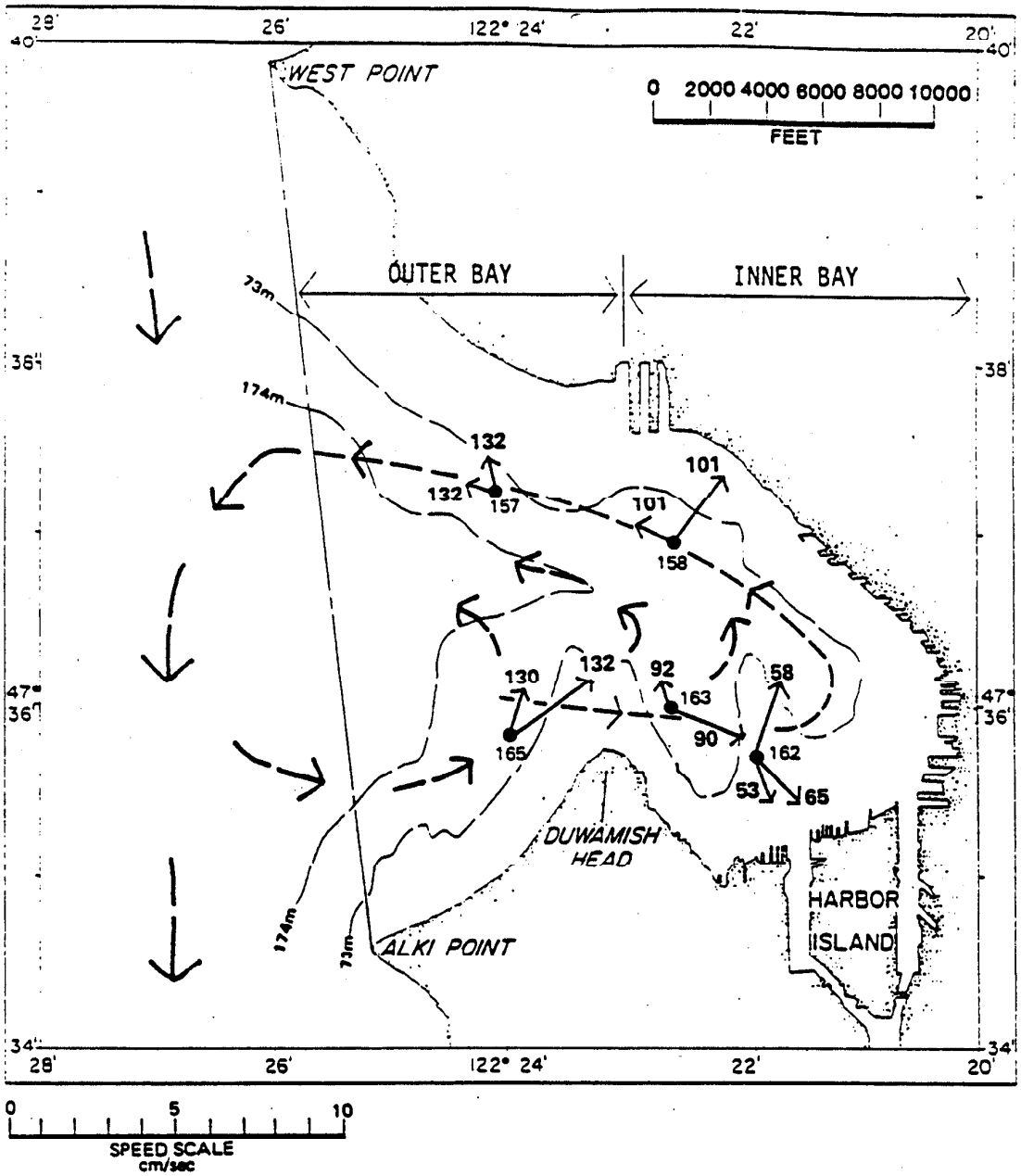
Figure 3. URS and Evans Hamilton (1984)



Net velocities (⟶) in Elliott Bay in the depth range of 50m - bottom at five locations (●). Numbers (157) denote sites and numbers (132) denote depth of observation in meters. Dashed line represents hypothetical trajectory of water particle.

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Figure 4. URS and Evans Hamilton (1984)

II. DISTRIBUTION OF SUSPENDED PARTICULATES

Most Useful References: 3, 4, 18, 19, 30, 32, 47, 98, 99

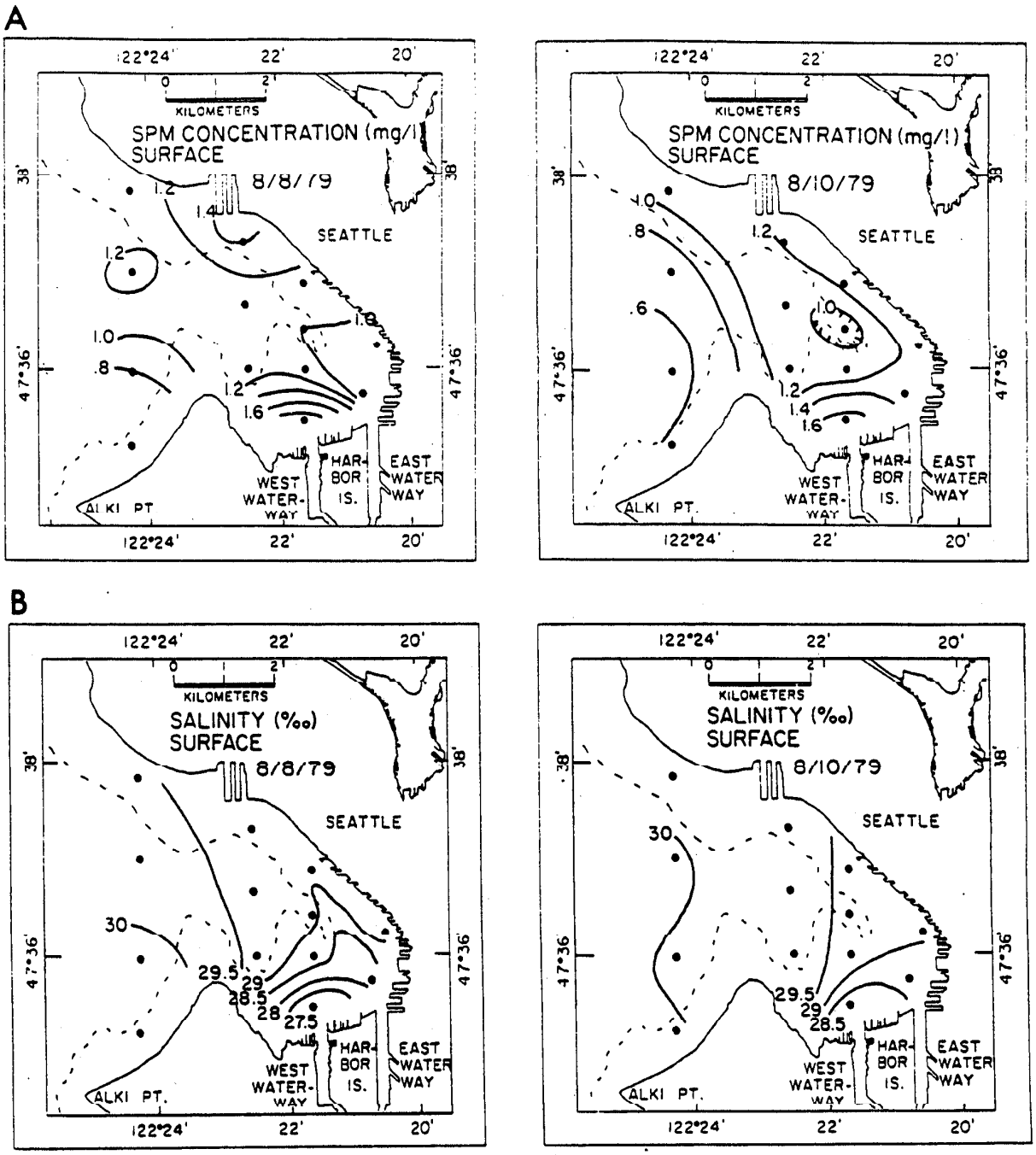
Other References: 17, 31, 37, 84, 101

Synopsis of Information Found: The horizontal and vertical distribution of suspended particulate matter (SPM) during NOAA's 1979-1980 field studies in Elliott Bay is described in Baker (1982) and Baker et al. (1983). These reports conclude the bulk of suspended particulate matter (SPM) occurs in a thin (<5m) surface layer from the Duwamish River plume and in a bottom nephloid layer in deep water areas (Figures 5 and 6). These reports also contain data on particle size distribution of SPM and organic content. Baker, *et al.*, (1983) conclude that, because of short residence time of Duwamish River water, the plume is a minor source of sediments to parts of Elliott Bay greater than 50m depth, but that "At shallower depths, shoreline sources and settling from the surface layer are probably the most important contributors to sedimentation." The distribution of SPM in Elliott Bay is also portrayed in Curl and Feely (1986), Curl, *et al.*, (1987, 1988), Feely, *et al.*, (1988), and Paulson, *et al.*, (1989), based on subsequent NOAA studies in 1985-1986 (Figures 7 and 8).

Tomlinson, *et al.*, (1980) studied the fate of particulates discharged by the Denny Way CSO. They had difficulty seeing the CSO plume because of a "massive," turbid plume from the Duwamish River, described as 1.5-3m deep and up to 1000m wide during storm events. The area "most heavily impacted" by the CSO plume extended 200-300m north and south of the discharge. Figure 9 shows a transverse section of the water column off the CSO. Helseth, *et al.*, (1979) and Stober and Chew (1984) contain hydrographic data that further demonstrate the Duwamish plume remains in the upper 5m along the Seattle waterfront.

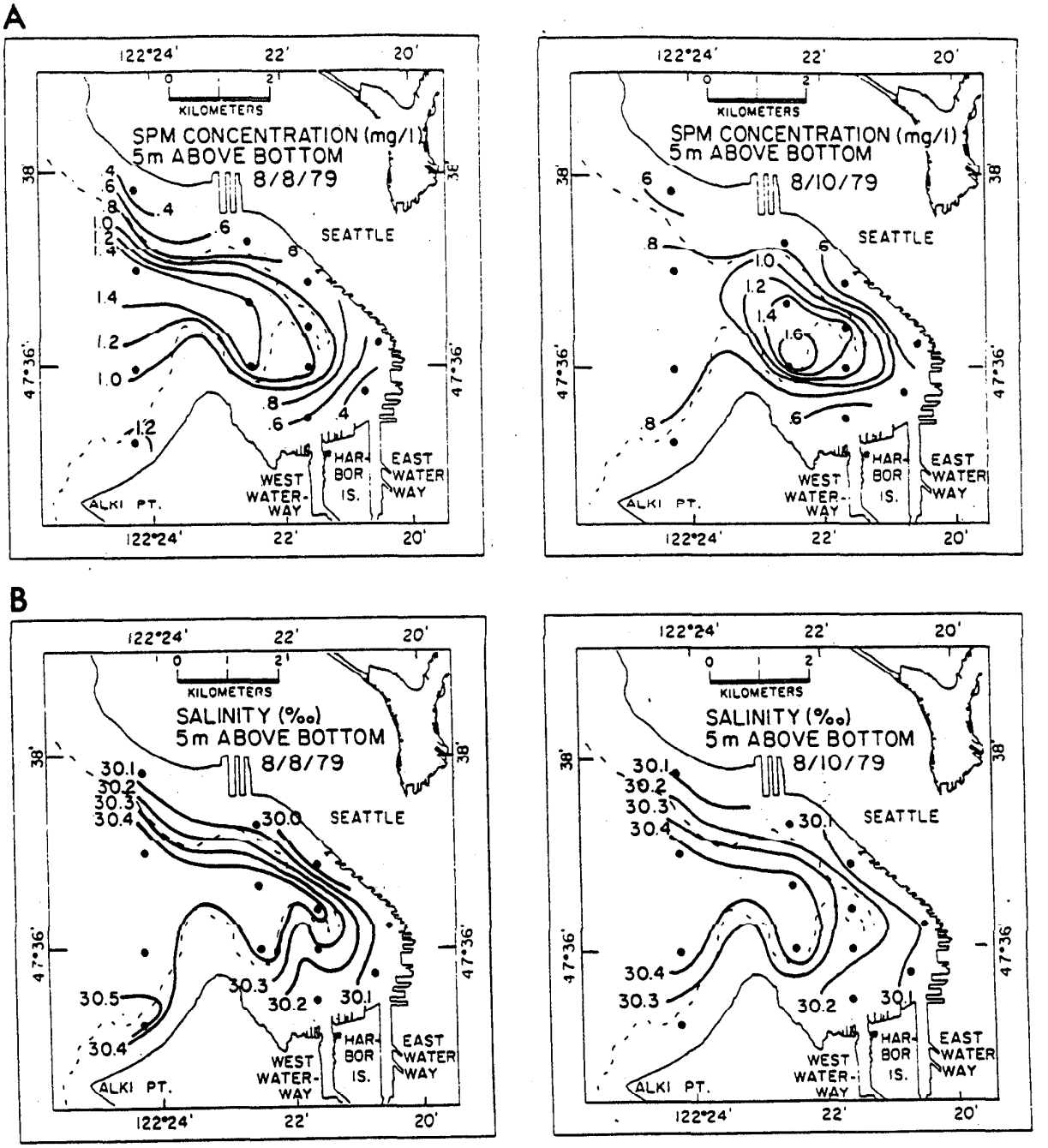
Sediment discharge by the Duwamish River is illustrated in Figure 10 (Curl, 1982). The season of maximum inputs to Elliott Bay is November through June.

Conclusion: The distribution of particulates in Elliott Bay has been described for a variety of conditions. The Duwamish River is expected to be the main influence on the study area, and may deposit sediments in nearshore areas along the waterfront.



Areal maps of surface (A) SPM concentration and (B) salinity at 1 m during the August surveys. Contour interval is 0.2 mg/l for SPM, 0.5°/₀₀ for salinity. Dotted line is the 100-m isobath.

Figure 5. Baker (1982)



Areal maps of bottom (A) SPM concentration and (B) salinity during the August surveys. Contour interval is 0.2 mg/l for SPM, 0.1°/₀₀ for salinity. Dotted line is the 100-m isobath.

Figure 5. Continued

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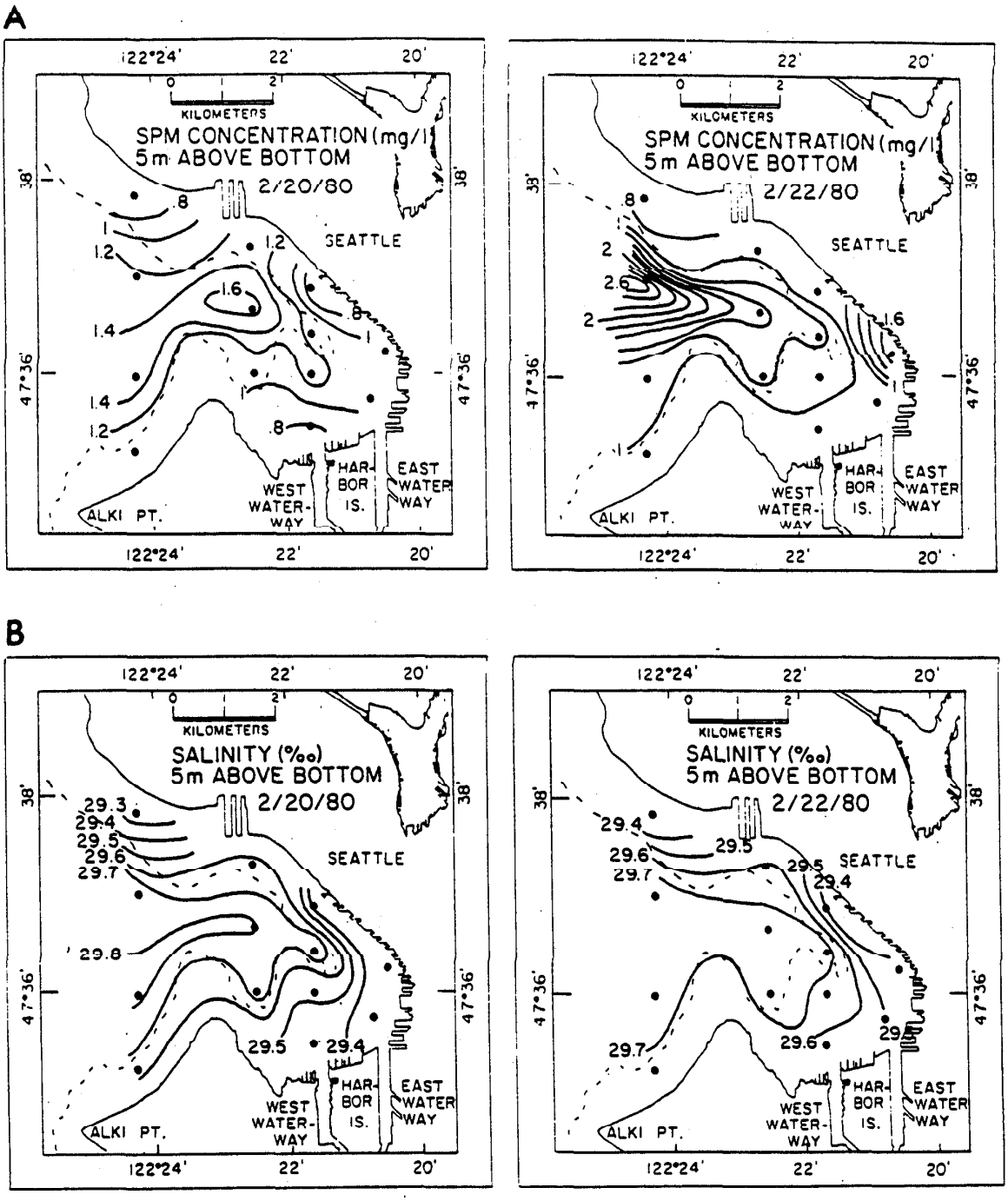
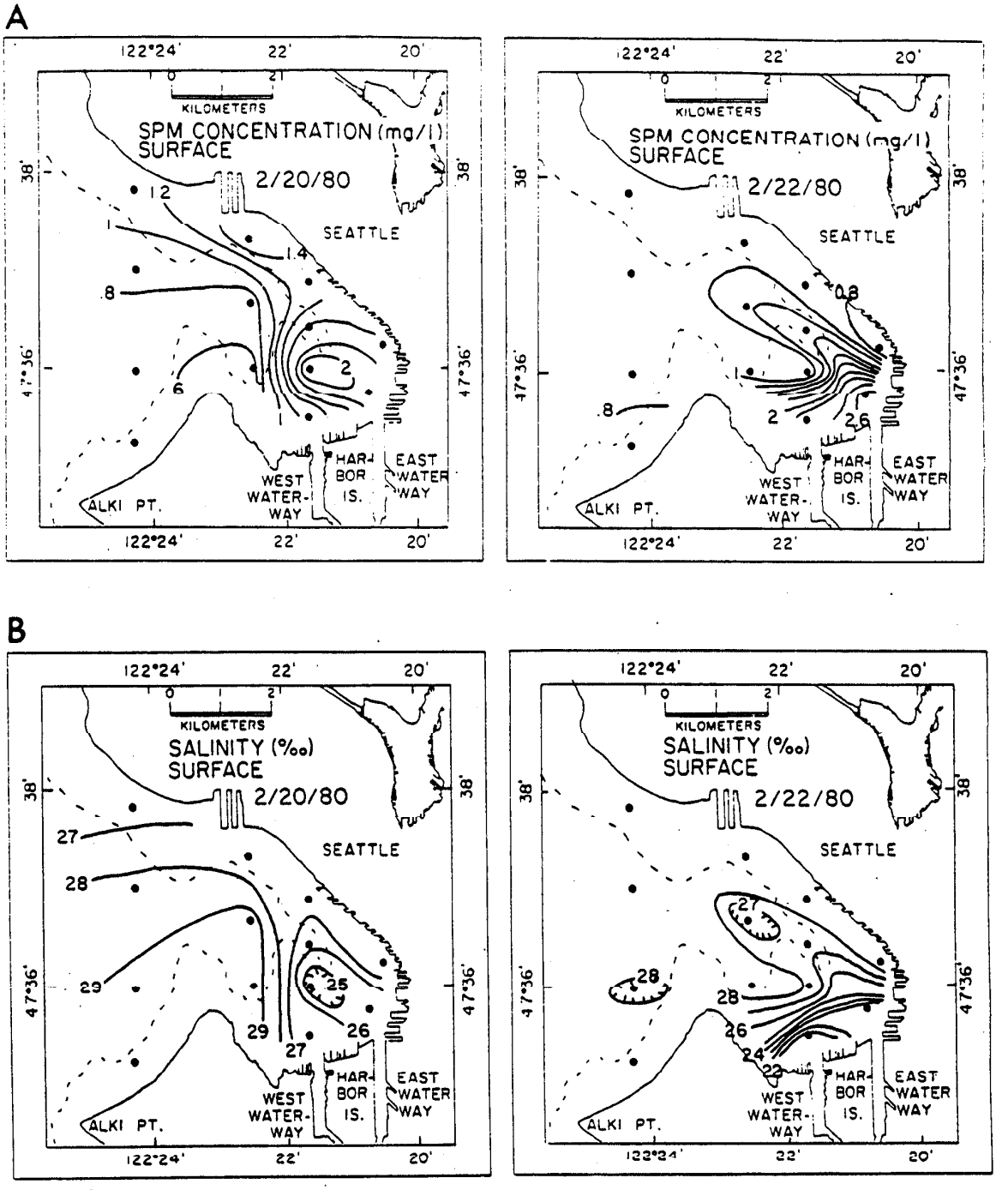


Areal maps of bottom (A) SPM concentration and (B) salinity during the February surveys. Contour interval is 0.2 mg/l for SPM, 0.1°/₀₀ for salinity. Dotted line is 100-m isobath.

Figure 6. Baker (1982)



Areal maps of surface (A) SPM concentration and (B) salinity at 1 m during the February surveys. Contour interval is 0.2 mg/l for SPM, 1°/₀₀ for salinity. Dotted line is 100-m isobath.

Figure 6. Continued

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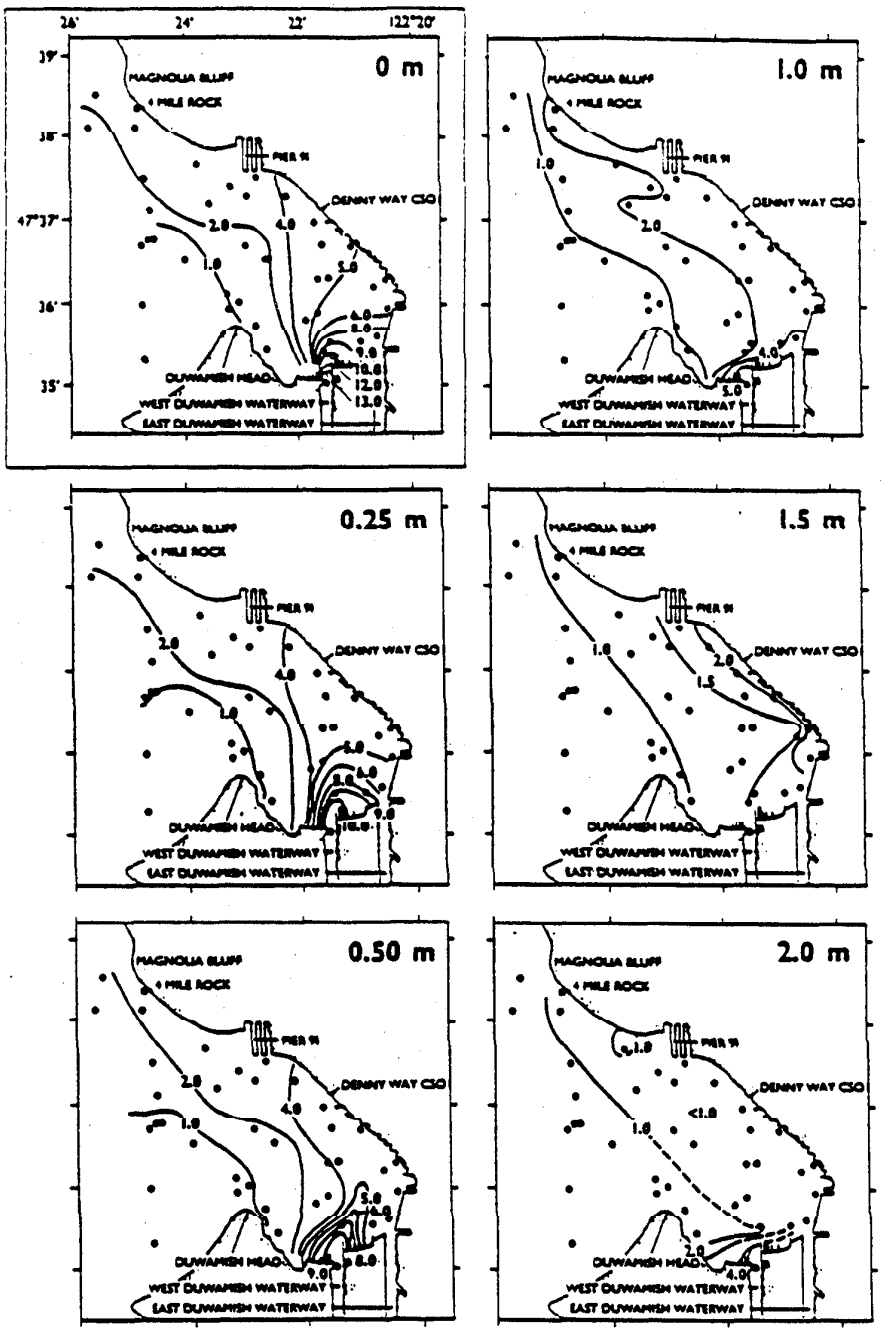


Near-Surface Concentrations of SPM (mg/l) Elliott Bay April 4, 1985

Figure 7. Curl *et al.* (1987)

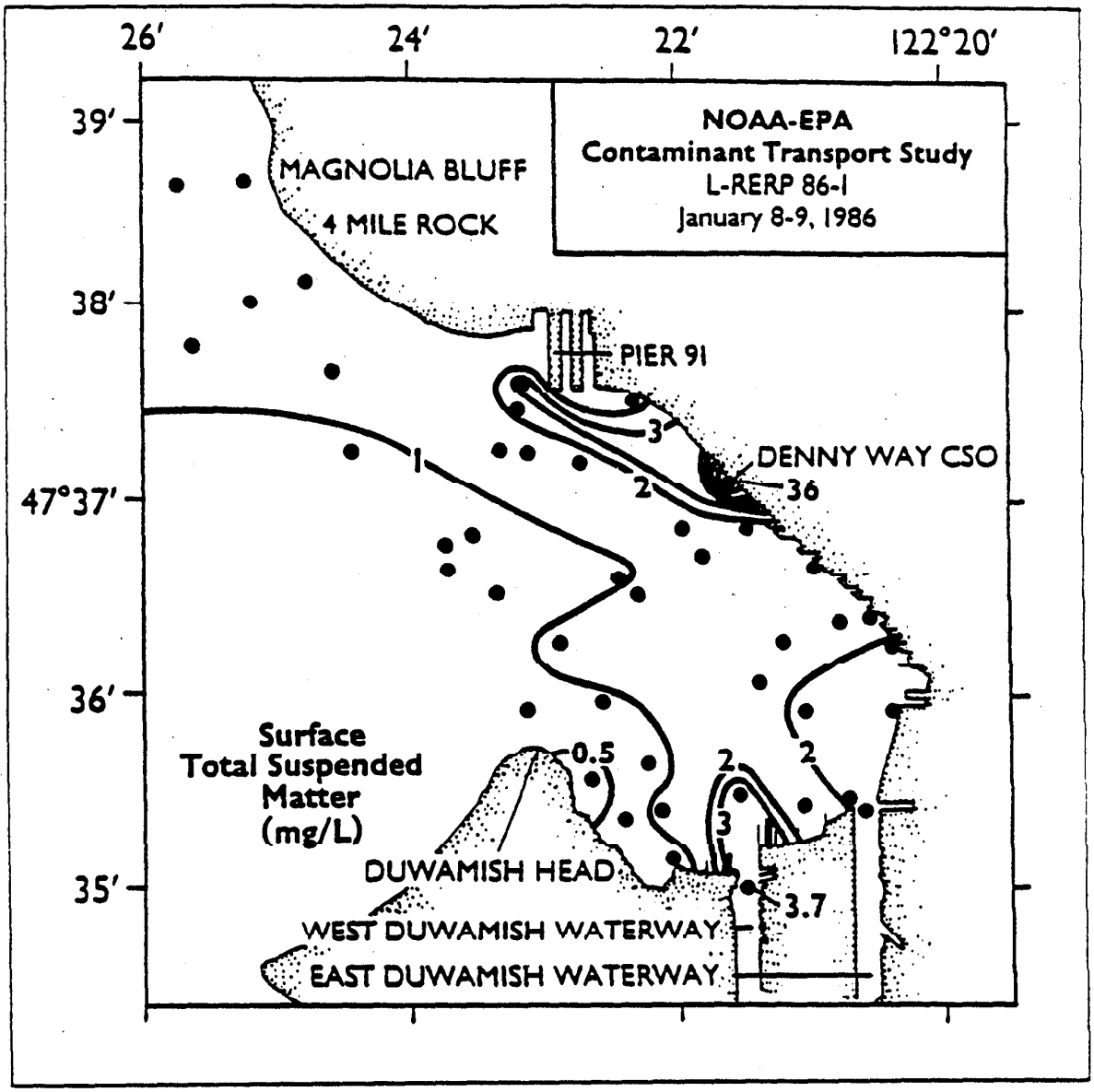
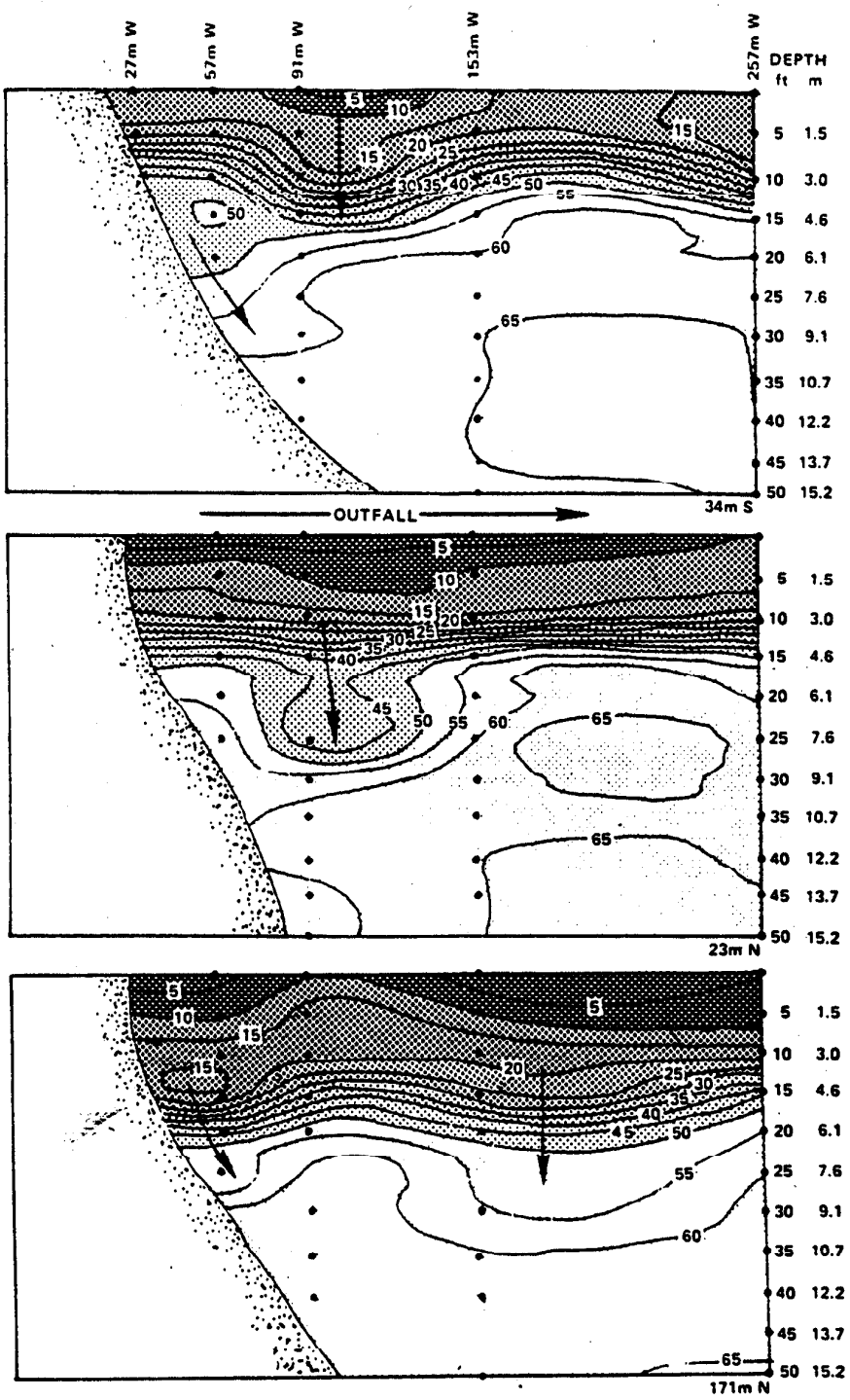
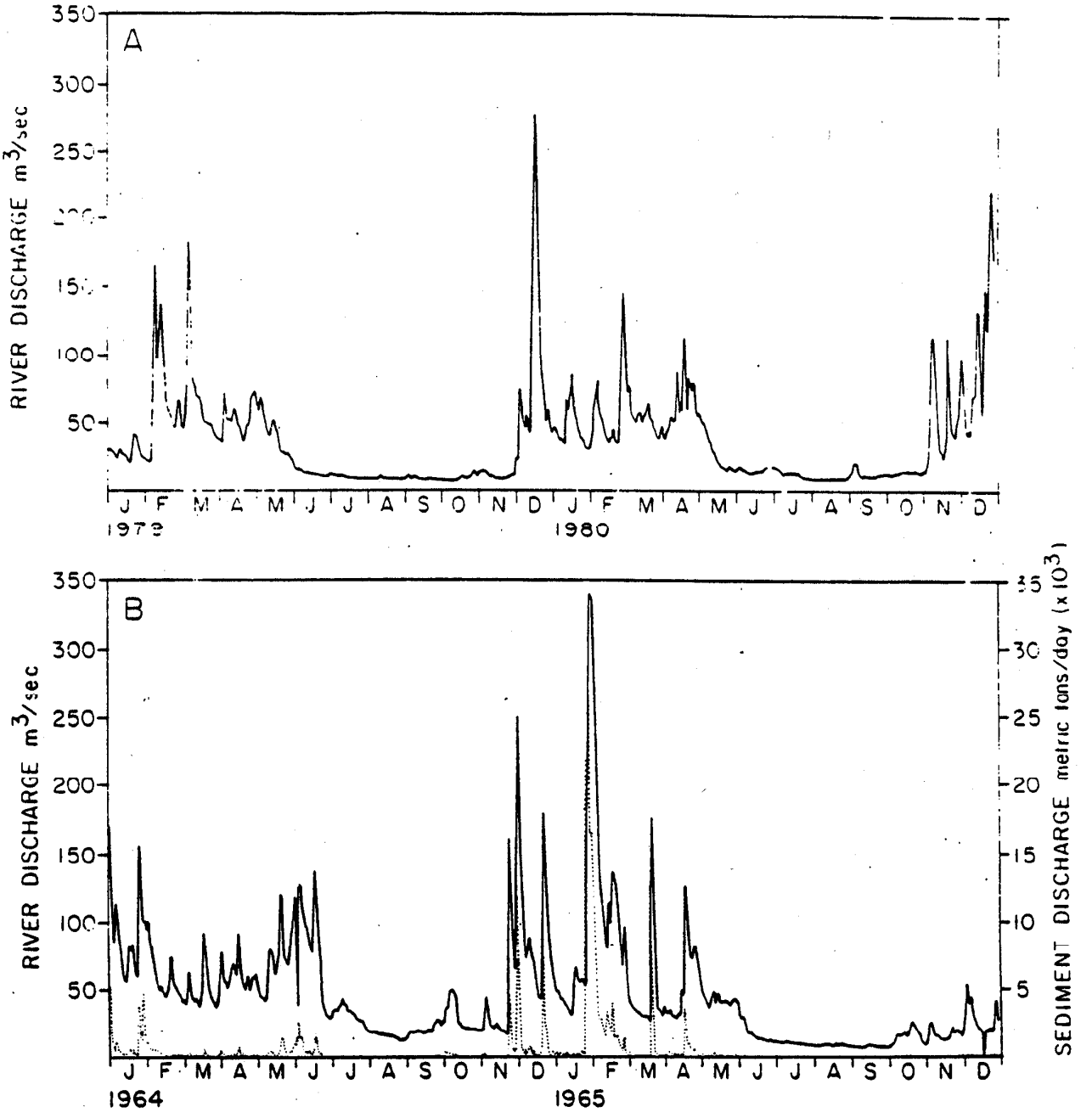


Figure 8. Curl et al. (1987)



Transverse sections of contours of percent light transmission around the overflow outfall of the Denny Way Regulator— 2050-2243 hrs., 2/24/79. The perspective is that of a diver looking south along the shoreline with Elliott Bay to his right. The arrows indicate areas of particulate settling.

Figure 9. Tomlinson *et al.* (1980)



Water discharge data for the Duwamish River at Tukwila (period of record: 1979-1980). B. water (-----) and sediment (.....) discharge data for the Duwamish River at Tukwila (period of record: 1964-1965). Data obtained from U.S. Geological Survey, Water Resources Division.

Figure 10. Curl (1982)

III. CHEMICAL ANALYSIS OF SUSPENDED PARTICULATES

Most Useful References: 15, 18, 19, 31, 32, 47, 57, 58, 59, 71

Other References: 21, 34, 63

Synopsis of Information Found: Chemical analysis of Elliott Bay and Duwamish River SPM has been conducted by a number of investigators; most reports deal with metals. NOAA's metals data pertinent to Elliott Bay are compiled in reports by Paulson, *et al.*, (1991a,b). Paulson, *et al.*, (1989) contains a useful summary table of 1980-1985 NOAA data on iron, manganese, lead, zinc, and copper concentrations in SPM (Table 1).

Riley, *et al.*, (1980) collected SPM samples off Pier 54, the Duwamish West Waterway and upper end of Harbor Island in July 1979 and analyzed a range of trace elements (Figure 11, Tables 2 and 3). Concentrations of arsenic and antimony in Duwamish River SPM are reported by Crecelius, *et al.*, (1975) for samples collected in 1972-1973.

Massoth, *et al.*, (1980) made early observations of enrichment of iron, chromium, nickel, zinc and copper in Duwamish SPM due to flocculation of dissolved metals. They noted concentration gradients of metals decreased more rapidly with distance from the Duwamish mouth than did SPM gradients, this attributed to dilution with particulates from other sources. Massoth, *et al.*, and Feely, *et al.*, (1983) discuss the importance of manganese oxides precipitating onto SPM and scavenging metals from the water column in Elliott Bay.

Curl (1987), Feely, *et al.*, (1988) and Paulson, *et al.*, (1989) describe the distribution of particulate metals in Elliott Bay based on the NOAA 1985 and 1986 samples (Figure 12). Curl (1987) ranked metals sources to Elliott Bay from highest to lowest as the West Duwamish Waterway, the north end of Harbor Island, the Denny Way CSO and the Seattle waterfront including the King Street CSO. The East Duwamish Waterway was a source of SPM, but not a significant contributor of metals.

Feely, *et al.*, (1988) concluded that, because of the short residence time of Duwamish River water "under most flow conditions, the great majority of trace metal contaminants are transported out of Elliott Bay..." Feely, *et al.*, (1988) calculated vertical fluxes of SPM, iron, manganese and lead were only about 0.5 - 2.3% of the horizontal fluxes.

Relative few data were found on concentrations of organic compounds in SPM. Pavlou and Dexter (1979) and Dexter, *et al.*, (1984) contain data on historic levels of polychlorinated biphenyls (PCBs). Riley, *et al.*, (1980) analyzed saturated and polynuclear aromatic hydrocarbons (PAH) in the above mentioned SPM samples collected of Pier 54 and elsewhere (Table 4). Hamilton and Bates (1984) discuss possible sources of saturated hydrocarbons in Duwamish River particulates.

More recent data on PAH and selected chlorinated organics are reported for the NOAA SPM samples collected in 1985-86 (Curl, *et al.*, 1987, 1988). The areal distribution of total PAH, including a station at the Denny Way CSO, is shown in Figure 13. Curl, *et al.*, concluded the major sources of PAH during April 1985 were along the Seattle waterfront and - in contrast to findings for metals - that the Duwamish was not a major source at this time. During wetter conditions in January 1986, the Denny Way CSO and West Duwamish Waterway were the major sources of PAH to Elliott Bay. PCB concentrations were described as low; DDT, DDE and DDD were below detection limits (Table 5).

Conclusion: Substantial data exist on the elemental composition of suspended particulates but similar information is limited for organics. Major particulate sources of metals and PAH to the bay have been ranked qualitatively. The Harbor Island area may have the potential to contribute significant concentrations of metals to the waterfront area, while during most seasons of the year, the major sources of PAHs to the waterfront area may be local.

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Elemental composition of suspended and settling particulates in Elliott Bay and the Duwamish River

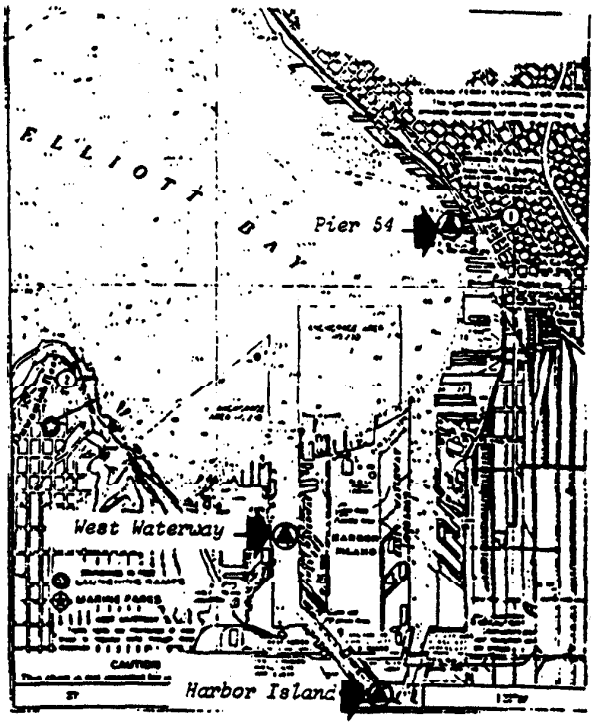
Sample location		Fe (wt%)	Mn (ppm)	Pb (ppm)	Zn (ppm)	Cu (ppm)	*n*
Green-Duwamish River		6·25[a]	1150[a]	45[b]	150[b]	42[b]	5
Suspended sediments		±2·00	±332	±9	±84	±6	
(1980–1984; sal = 0)		(*n* = 7)					
Head of West Duwamish							
Waterway Suspended matter		7·72	1595	59	137	106	1
(April 1985; sal = 8·4)							
Elliott Bay		7·90	1700	86	183	113	14
Suspended matter		±1·06	±88	±36	±27	±11	
(April 1985; sal = 10–26)	RSTD	13%	5%	43%	15%	10%	
Elliott Bay							
Settling particulates (6 m)		4·25	553	100	—	52	1
(April 1985)							
Elliott Bay[c]		6·91	4100	370	300	127	18
Suspended matter		±2·00	±1700	±182	±85	±24	
(Feb 1980)	RSTD	29%	41%	49%	28%	19%	

RSTD: Relative standard deviation.
[a]Massoth *et al.*, 1982.
[b]Paulson *et al.*, 1988.
[c]Feely *et al.*, 1983.

Table 1. Paulson *et al.* (1989)

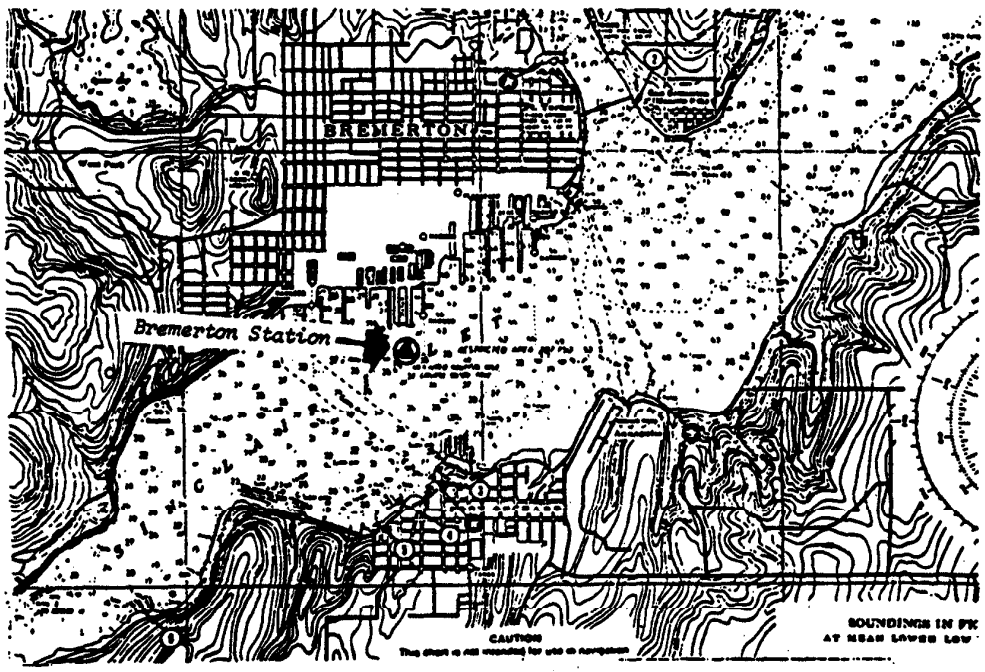
ELLIOT BAY AREA

Stations: *Pier 54*
Harbor Island
West Waterway



SINCLAIR INLET AREA

Bremerton Station



Maps of Elliott Bay area and Sinclair Inlet area showing locations of Pier 54, Harbor Island, West Waterway and Bremerton sampling stations.

Figure 11. Riley *et al.* (1980)

Concentration of Elements in Puget Sound Suspended Matter Collected July 1979 ppm Dry Weight
(mean values from duplicate samples, uncertainties of approximately ± 20% for σ)

ELEMENT	Pier 54	Harbor Island	West Waterway	Puyallup River	Hylebos Waterway	Blair Waterway	Bremerton	Olympia	Port Madison
As	<22	37	44	<22	94	52	31	<22	28
Br	58	78	75	179	303	95	126	34	214
Co	8.5	7.5	14	2.5	8.8	8.2	7.4	2.2	6.4
Cr	79	52	88	26	66	54	80	24	60
Cu	230	179	208	56	226	156	130	47	68
Eu	0.39	0.52	0.94	0.22	0.68	0.68	0.41	0.11	0.28
Mn	1850	1050	1090	373	581	660	1730	146	2090
Ni	82	39	44	47	55	28	58	12	55
Pb	380	338	448	153	250	111	146	26	97
Rb	27	33	39	25	18	37	24	8	<20
Sb	2.9	3.8	9.8	0.7	9.0	4.7	3.5	0.4	1.0
Se	2.3	1.1	1.2	0.5	1.6	1.2	1.7	1.5	1.8
Sr	205	213	213	262	370	328	<200	<200	<200
V	51	62	106	22	80	59	53	22	36
Zn	900	540	580	360	380	340	490	180	280

Table 2. Riley *et al.* (1980)

Concentration of Elements in Puget Sound Suspended Matter Collected July 1979 % Dry Weight
(mean values from duplicate samples, uncertainties of approximately ±20% for σ)

ELEMENT	Pier 54	Harbor Island	West Waterway	Puyallup River	Hylebos Waterway	Blair Waterway	Bremerton	Olympia	Port Madison
Al	3.7	7.1	6.6	6.3	8.1	6.1	4.2	0.2	1.4
Ca	0.7	1.6	1.5	2.3	2.2	2.6	1.4	0.6	0.8
Cl	0.30	0.83	0.43	4.8	0.74	1.2	1.5	0.53	2.9
Fe	4.0	5.9	5.4	1.9	3.9	3.3	2.8	0.5	1.4
K	0.33	0.78	0.76	0.86	0.89	0.86	0.52	0.15	0.37
P	0.75	1.0	0.59	0.66	0.62	0.67	0.67	0.48	0.72
S	0.55	0.38	0.30	0.49	0.44	0.54	0.55	0.53	0.66
Si	15	22	20	18	25	28	19	2	11
Ti	0.16	0.33	0.36	0.32	0.30	0.38	0.45	0.04	0.15

Table 3. Riley *et al.* (1980)

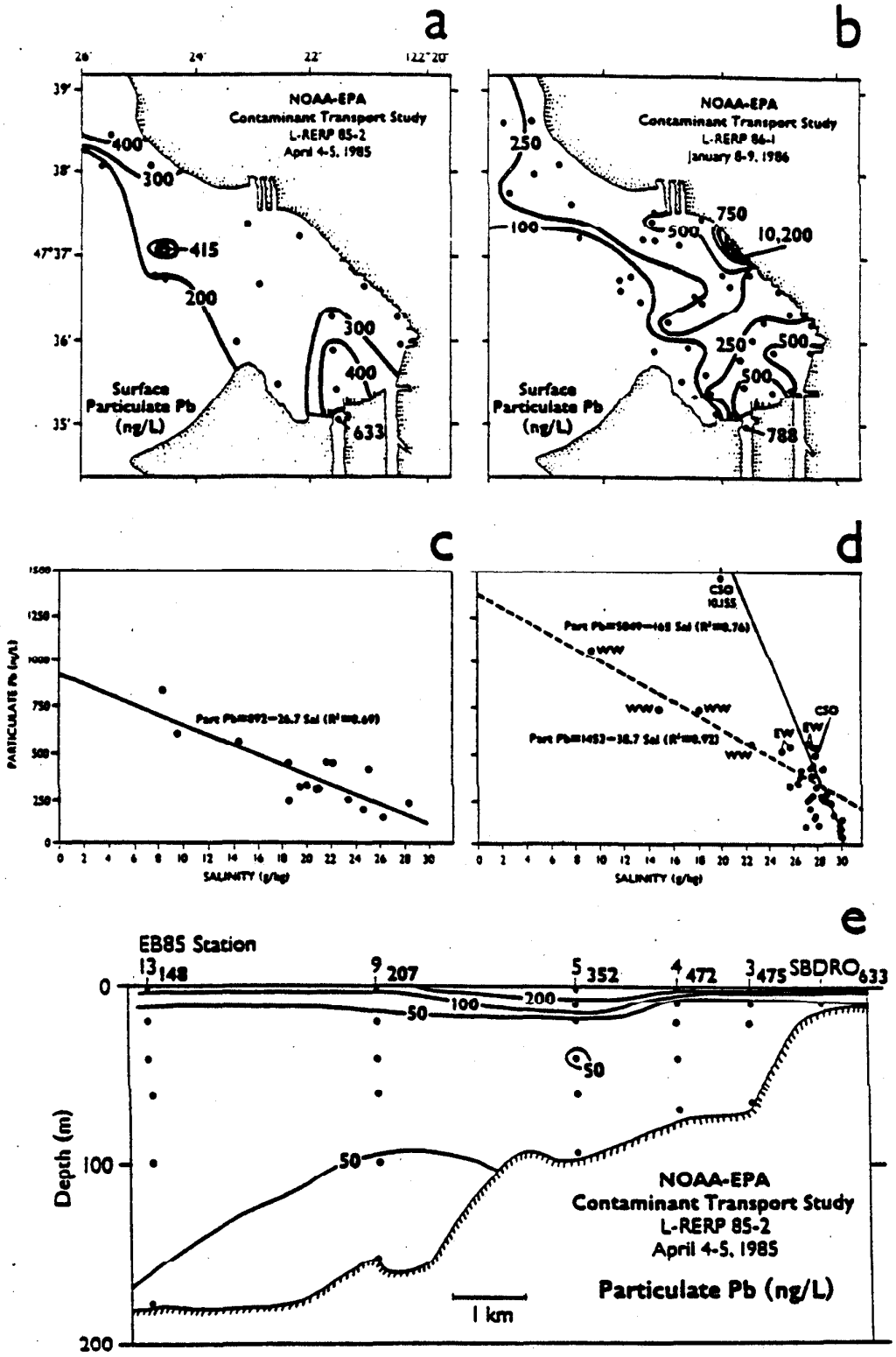


Figure 12. Curl *et al.* (1987)

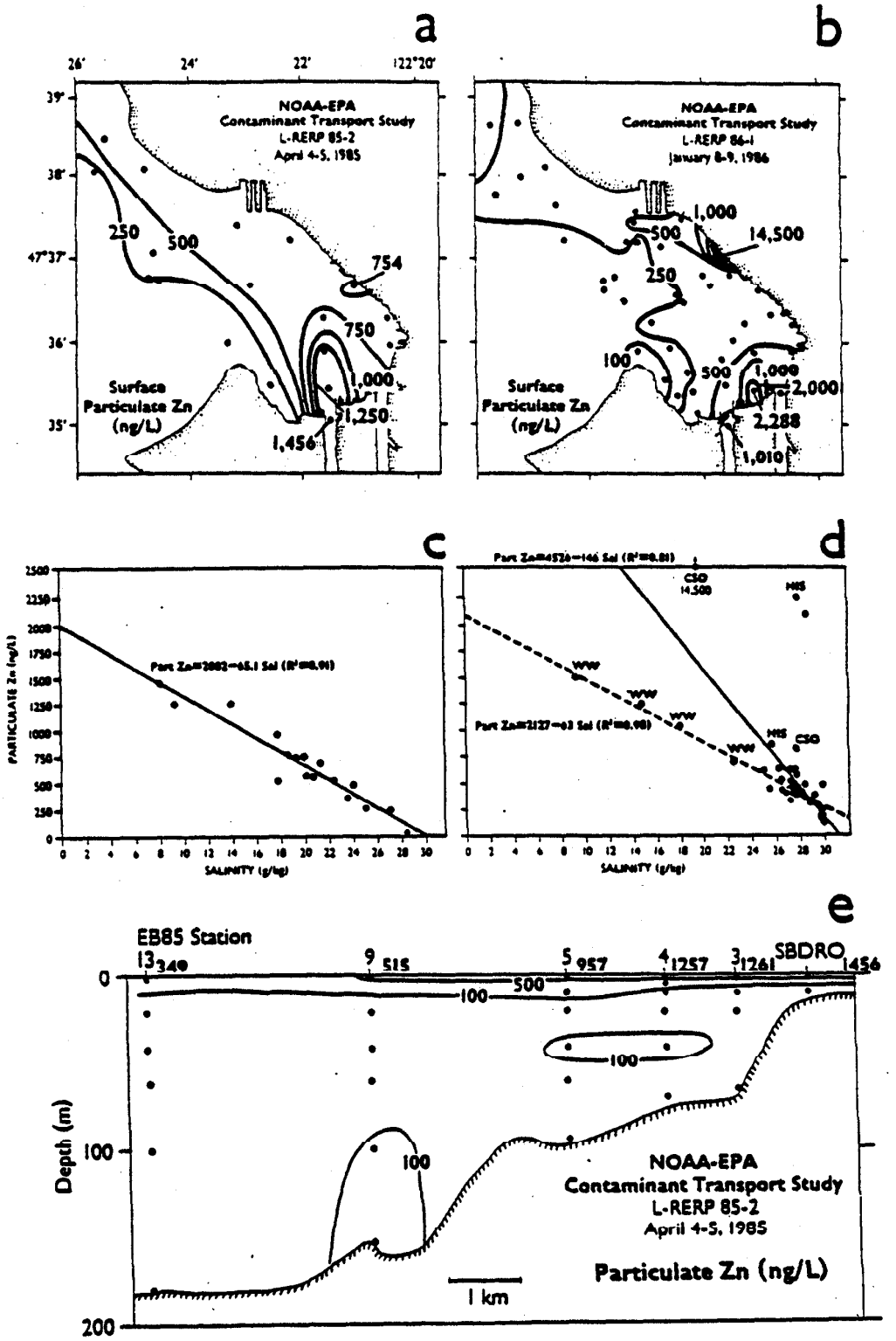


Figure 12. Continued

Concentrations of Aromatic Hydrocarbons Associated with Suspended Matter from Nine Sampling Sites in Puget Sound, $\bar{x} \pm SE$, Parts Per Million (ppm) Dry Weight Sediment

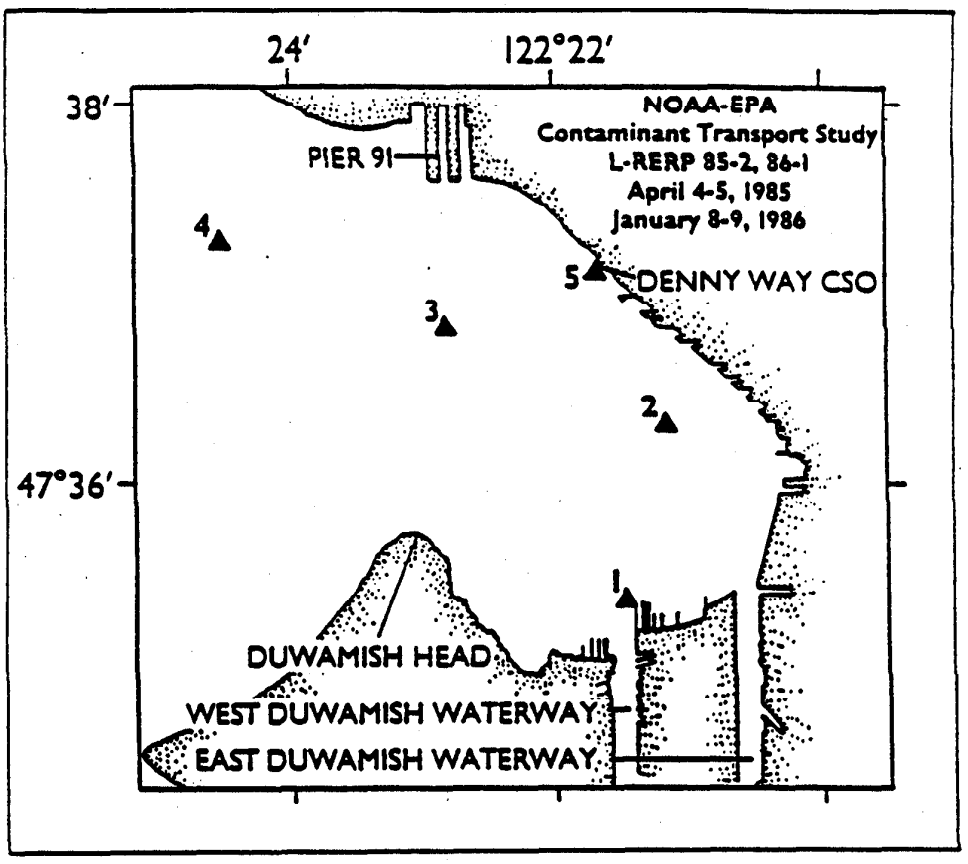
Compound	Seattle P-54[1]	Seattle HI	Seattle WW	Bremerton SI	Tacoma PR	Tacoma HW	Tacoma BW	Olympia BI	Port Madison
Naphthalene	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	0.03 ± 0.00	0.42 ± 0.14	0.05 ± 0.03	0.23 ± 0.08	0.02 ± 0.00	0.02 ± 0.01
2-MN[2]	0.02 ± 0.00	0.02 ± 0.01	0.02 ± 0.00	0.02 ± 0.01	0.03 ± 0.00	0.02 ± 0.01	0.01 ± 0.01	0.05 ± 0.03	0.01 ± 0.00
1-MN	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	0.03 ± 0.02	0.02 ± 0.00	0.02 ± 0.02	0.01 ± 0.01	0.19 ± 0.14	0.17 ± 0.21
2,6-DMN	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.00	0.07 ± 0.01	<0.01	0.10 ± 0.11	0.05 ± 0.06	0.03 ± 0.03	0.10 ± 0.07
1,3-DMN	<0.01	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.01	0.01 ± 0.01	0.14 ± 0.11	<0.01	0.02 ± 0.01	0.02 ± 0.00
2,3-DMN	0.01 ± 0.01	0.01 ± 0.00	<0.01	0.02 ± 0.00	<0.01	0.02 ± 0.03	0.02 ± 0.02	0.01 ± 0.01	0.01 ± 0.01
2,3,6-TMN	0.02 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.13 ± 0.07	0.07 ± 0.03	0.73 ± 0.64	0.03 ± 0.05	0.04 ± 0.01	0.06 ± 0.09
Fluorene	0.05 ± 0.01	0.04 ± 0.06	<0.01	0.07 ± 0.10	0.04 ± 0.06	<0.01	<0.01	0.05 ± 0.01	0.01 ± 0.02
Phenanthrene	0.27 ± 0.03	0.14 ± 0.09	0.22 ± 0.04	0.10 ± 0.04	0.27 ± 0.06	0.62 ± 0.26	0.28 ± 0.13	0.12 ± 0.13	0.08 ± 0.02
Anthracene	0.18 ± 0.02	<0.01	0.08 ± 0.02	<0.01	<0.01	0.13 ± 0.18	<0.01	0.09 ± 0.04	0.41 ± 0.44
1-MP	0.01 ± 0.02	0.01 ± 0.01	<0.01	0.05 ± 0.02	0.06 ± 0.02	0.19 ± 0.26	0.22 ± 0.04	0.01 ± 0.01	0.05 ± 0.06
2-MP	0.04 ± 0.02	0.10 ± 0.08	0.08 ± 0.03	0.10 ± 0.00	0.22 ± 0.16	0.48 ± 0.68	0.45 ± 0.64	0.10 ± 0.14	0.34 ± 0.24
Fluoranthene	0.37 ± 0.05	0.25 ± 0.09	0.36 ± 0.11	0.54 ± 0.33	2.34 ± 0.44	0.83 ± 0.08	3.45 ± 1.62	0.08 ± 0.02	0.15 ± 0.00
Pyrene	0.49 ± 0.17	0.21 ± 0.20	0.58 ± 0.21	0.97 ± 0.49	3.94 ± 0.94	0.51 ± 0.71	2.94 ± 1.29	0.21 ± 0.09	1.05 ± 0.40
1-Me-Pyrene	<0.01	<0.01	<0.01	<0.02	<0.01	0.11 ± 0.15	<0.02	<0.01	<0.01
B(a)A	0.08 ± 0.00	0.03 ± 0.01	0.07 ± 0.02	<0.02	<0.01	0.01 ± 0.01	<0.01	<0.01	<0.01
Chrysene	0.13 ± 0.00	0.05 ± 0.00	0.12 ± 0.04	<0.01	<0.01	0.04 ± 0.06	<0.01	<0.01	<0.01
B(a)P	0.02 ± 0.03	<0.01	<0.01	<0.01	0.12 ± 0.17	0.04 ± 0.05	<0.01	<0.01	<0.01
Perylene	0.03 ± 0.04	<0.01	<0.01	<0.01	0.18 ± 0.26	0.06 ± 0.09	<0.01	<0.01	<0.01
TOTAL	1.76 ± 0.07	0.90 ± 0.15	1.6 ± 0.50	2.1 ± 0.73	7.71 ± 0.93	4.08 ± 1.02	7.67 ± 1.37	1.01 ± 0.62	2.48 ± 0.05

[1]P-54 = Pier 54, HI = Harbor Island, WW = West Waterway, SI = Sinclair Inlet, PR = Puyallup River, HW = Hylebos Waterway, BW = Blair Waterway, BI = Budd Inlet

[2]MN = methylnaphthalene, DMN = dimethylnaphthalene, TMN = trimethylnaphthalene, MP = methylphenanthrene, 1-Me-Pyrene = 1-methylpyrene, B(a)A = Benz(a)anthracene, B(a)P = Benz(a)pyrene

Table 4. Riley *et al.* (1980)

PAH CONCENTRATIONS IN ELLIOTT BAY



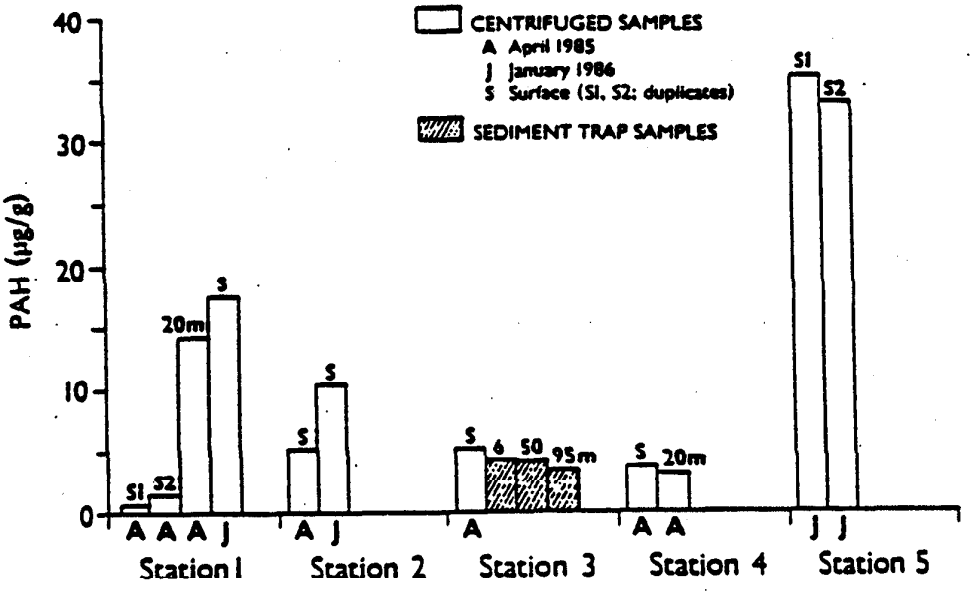


Figure 13. Curl *et al.* (1987)

TRACE ORGANICS
(in total ng/g)
COLLECTED BY CENTRIFUGE 1/86

SAMPLE NAME	S1SURF1	S1SURF2	S2SURF	S3SURF
DATE/TIME	10886, 1250	10886, 1250	10986, 0950	11086, 0915
LATITUDE	47°37.1'N	47°37.1'N	47°35.0'N	47°36.6'N
LONGITUDE	122°21.6'W	122°21.6'W	122°21.5'W	122°21.3'W
LOCATION	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY	ELLIOTT BAY
VOL SAMPLED	140L	193L	510L	525L
Phe	15000	14000	1100	950
Ant	3000	2700	380	420
MPh	24000	22000	1300	960
Fla	12000	13000	3600	2100
Pyr	9400	9000	3400	1800
Ret	<320	<310	230	260
BAA	2100	1900	950	730
Chr	2900	2500	1600	1100
BF1	3100	2000	3100	2200
BEP	1400	1200	1400	720
BAP	1800	1300	1200	790
IPy	1400	1100	1200	670
BPe	1400	1100	1100	620
DDE	<8.8	<12	<2.1	<1.6
DDT	<35	<50	<8.5	<6.5
DDD	<35	<50	<2.1	<6.5
CL2	<8.5	<12	<2.1	<1.6
CL3	<8.5	32	<2.1	<1.6
CL4	<14	25	<3.4	<2.6
CL5	86	25	28	10
CL6	160	19	84	59
CL7	100	36	59	29
CL8	<14	<20	11	<2.6
CL9	<28	<40	<6.8	<5.2

Table 5. Curl et al. (1987)

IV. BOTTOM SEDIMENT SURVEYS

Most Useful References: 22, 36, 49, 50, 69, 77-79, 90, 92-94

Other References: 9, 12, 15, 16, 21, 25, 26, 28, 29, 39, 41, 42, 45, 46, 51, 62, 72-75, 83-89, 91, 93-96, 103

Synopsis of Findings: Dexter, *et al.*, (1981) reviewed results of sediment surveys in Elliott Bay from reports published up to 1980. More recently, Tetra Tech (1986) evaluated approximately 70 reports on chemical contaminants in Elliott Bay. Seven reports were selected by Tetra Tech for a detailed analysis of sediment chemistry: Romberg, *et al.*, (1984), Malins, *et al.*, (1980, 1982), Dexter, *et al.*, (1984), Stober and Chew (1984), and EPA (1982, 1983). Station locations of these studies are in Figure 14.

Based on elevations above reference areas, Tetra Tech concluded the Seattle Waterfront between Pier 91 and Terminal 37 was among the most contaminated areas of Elliott Bay for LPAH, HPAH and PCBs. Copper, lead and zinc were also high, especially along the south waterfront area (Pier 70 to Terminal 37). The contamination between Pier 91 - Pier 70 was primarily at sampling stations clustered around the Denny Way CSO. This contaminated area extended a "few thousand feet along the beach and offshore from the end of the pipe." Figures in the Tetra Tech report show the spatial distribution of grain size, total organic carbon (TOC), and selected contaminants in the bay (e.g., Figure 15).

Following the above review, a 1985 field investigation of the nearshore Elliott Bay/Duwamish River was conducted to identify problem sediments in shallow water areas (< 20m) between Alki Point and West Point (PTI and Tetra Tech, 1988). The "Seattle South Waterfront" from Pier 70 to Terminal 37 (Figure 16) corresponds to the resuspension study area. Sampling sites near the Denny Way CSO were limited to one intertidal station (NS-01) because of the extensive data available in Romberg, *et al.*, (1984). Figure 17 shows Tetra Tech's sampling sites.

The Seattle South Waterfront, North Harbor Island and West Waterway were the most contaminated areas. Results of sediment chemistry are summarized with bar graphs (Figure 18). Contour maps using codes for concentration levels compare survey results with historical data (e.g., Figures 19 and 20). A modified excerpt from PTI and Tetra Tech (1988) summarizes findings for the Seattle South Waterfront (see pages 248-251 for complete text):

"The sediments were highly contaminated throughout and had more chemicals exceeding HAET (highest apparent effects thresholds) than in any other problem area. Superimposed upon the high levels of certain problem chemicals (e.g., PAH and mercury) were maximum concentrations of different problem chemicals occurring at a number of non-adjacent stations. These patterns suggested that multiple local sources were present, perhaps in conjunction with a more diffuse source for compounds such as PAH.

PAH were the most commonly occurring problem chemicals and exceeded the HAET at 14 of 15 stations. HAET for other organic compounds (e.g., PCBs, 1,4-dichlorobenzene and chlorinated pesticides) and a number of metals (including cadmium, copper, lead, zinc, mercury and silver) were exceeded at least once. The highest concentrations of many problem chemicals occurred at Stations SS-08 (Pier 63-64) and SS-09 (Pier 65-66). Although these stations were not located near obvious potential sources, a number of stations are near CSOs: SS-03 (King St.), SS-04 (Washington St.), SS-05 (Madison St.), SS-06 (University St.), and SS-11 (Vine St.). Sediments throughout the problem area tended to be fine-grained and rich in organic matter.

Concentrations of PAH decreased in either direction from the extremely high concentrations at Station SS-08 (Pier 63-66) (roughly 0.38 percent DW of the EPA priority pollutant hydrocarbons) and tended to correlate well with TOC. Detection limits for low molecular weight PAH (LPAH) were very high at Station SS-12 (Pier 70-71), which may explain why HAET for PAH were not exceeded at this station.

The most elevated metals in this area had similar overall distribution patterns. For the metals of highest concentrations, concentrations were relatively constant and elevated throughout the area, with pronounced maxima at non-adjacent stations (typically SS-03 (Pier 42), SS-09 (Pier 65-66), and historical TPSS Station S0090 (Romberg, *et al.*, 1984). Examples of these distributions include mercury, zinc, lead, cadmium and arsenic. Copper distributions were somewhat more variable but maximized at SS-03 and SS-07 (Pier 57-59). Notably, chromium and nickel concentrations maximized at Station SS-10 (Pier 66-67) and were the highest values observed in the study. Chromium and nickel were near or below reference levels at other stations in the problem area.

PCB concentrations were generally elevated but patchy. 1,4-dichlorobenzene exceeded HAET at Stations SS-09 (Pier 65-66) and SS-03 (Pier 42), but high detection limits occurred at other stations. Benzyl alcohol exceeded HAET at Station SS-03 (Pier 43)."

An evaluation of potential sources of sediment contamination followed the 1985 survey (Tetra Tech, 1988a). Most of the material in this useful report was outside the scope of the literature search. It contains figures showing locations of nearshore sediment sampling stations from previously mentioned surveys along the Seattle Waterfront (Figures 21 and 22).

Tetra Tech (1988b,c) evaluate sediment remediation and recovery off the Denny Way CSO and Slip 4 in the Duwamish River. These reports contain figures showing the areal distributions of mercury, zinc, fluoranthene, chrysene, butyl benzyl phthalate, bis(2-ethylhexyl)phthalate and PCBs in sediments off the Denny Way CSO based on surveys by Malins, *et al.*, (1980), Romberg, *et al.*, (1984), Romberg, *et al.*, (1987) and PTI and Tetra Tech (1988). A summary of station locations is shown in Figure 23. Mercury concentrations are summarized in Figure 24.